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DISEASE DETECTION SURVEY
Air Pollution

Arizona and New Mexico
Region 3

1973

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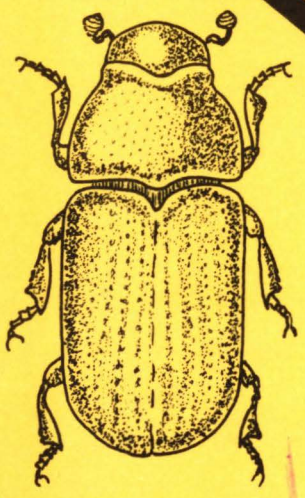

Southwestern Region

U. S. DEPARTMENT OF AGRICULTURE

FOREST SERVICE

5220

RMO

R-3 73-24

DISEASE DETECTION SURVEY
Air Pollution

Arizona and New Mexico
Region 3

1973

Branch of Forest Insect and Disease Management
Division of Timber Management
Southwestern Region, USDA, Forest Service
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FOREST SERVICE
Region 3
517 Gold Avenue, SW
Albuquerque, New Mexico 87101

5220

June 25, 1973

To All Survey Cooperators and
Interested Individuals

The report, entitled "Disease Detection Survey, Air Pollution, Arizona and New Mexico, Region 3," is enclosed for your information. This report summarizes the results of a survey conducted to determine if SO_2 from existing major sources was causing injury to forest vegetation in New Mexico and Arizona, and to collect background information where major sources are expected in the near future.

Mark M. Johannesen

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Assistant Regional Forester
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CONTENTS

	Page
ABSTRACT	ii
LIST OF TABLES	iii
LIST OF FIGURES	v
INTRODUCTION	1
METHOD	5
RESULTS	7
Group I.--Aztec Ruins National Monument; Chuska Mountains, Navajo Indian Reservation; Jicarilla Ranger District, Carson National Forest; Cuba Ranger District, Santa Fe National Forest; Mesa Verde National Park	7
Group II.--Coronado National Memorial; Douglas Ranger District, Coronado National Forest; Patagonia Ranger District, Coronado National Forest	27
Group III.--Lake Mohave Ranger District, Lake Mead National Recreation Area	33
Group IV.--Glen Canyon National Recreation Area; Navajo Mountain, Navajo Indian Reservation; North and South Rim, Grand Canyon National Park; Jacob Lake Ranger District, Kaibab National Forest	36
Group V.--Silver City Ranger District, Gila National Forest; Mimbres Ranger District, Gila National Forest; Wilderness Ranger District, Gila National Forest; Glenwood Ranger District, Gila National Forest	53
Group VI.--Santa Catalina Ranger District, Coronado National Forest	67
Group VII.--Clifton Ranger District, Apache National Forest	76
Group VIII.--Tonto National Monument; Sierra Ancha Experimental Forest; Globe Ranger District, Tonto National Forest; Roosevelt Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest	89
Sulfation Plate Reliability	112
SUMMARY	112
PLANS FOR FUTURE WORK	113
ACKNOWLEDGMENTS	115
LITERATURE CITED	116

ABSTRACT

A detection survey was conducted to determine if SO_2 from existing major sources was causing injury to forest vegetation in New Mexico and Arizona. In addition, background information was collected in areas where major sources are expected in the near future.

Symptoms of acute SO_2 injury were found on the Tonto National Forest, near Miami, Arizona; on the Coronado National Forest, near San Manuel, Arizona; and on the Apache National Forest, near Morenci, Arizona. Symptoms which resembled SO_2 injury, but need further evaluation, were noted near Hurley, New Mexico. No areas were found where trees were being killed by SO_2 fumigation.

LIST OF TABLES

Table	Title	Page
1	Estimates of pollutant emissions from major sources in New Mexico and Arizona	2
2	Pollution sources and survey area groups	8
3	Sulfation plate data, Aztec Ruins National Monument	14
4	Sulfation plate data, Mesa Verde National Park	15
5	Sulfation plate data, Jicarilla Ranger District, Carson National Forest	17
6	Sulfation plate data, Cuba Ranger District, Santa Fe National Forest	18
7	Sulfation plate data, Chuska Mountains, Navajo Indian Reservation	20
8	Sulfation plate data, Coronado National Memorial	29
9	Sulfation plate data, Douglas Ranger District, Coronado National Forest	30
10	Foliage analysis for total sulfur, Glen Canyon National Recreation Area	42
11	Foliage analysis for sulfate sulfur, Glen Canyon National Recreation Area	43
12	Soil analysis results, Glen Canyon National Recreation Area	44
13	Sulfation plate data, Navajo Mountain, Navajo Indian Reservation	45
14	Sulfation plate data, Jacob Lake Ranger District, Kaibab National Forest	46
15	Sulfation plata data, Grand Canyon National Park	48
16	Sulfation plate data, Silver City Ranger District, Gila National Forest	57

Table	Title	Page
17	Sulfation plate data; Mimbres Ranger District, Gila National Forest; Wilderness Ranger District, Gila National Forest; Glenwood Ranger District, Gila National Forest	60
18	Sulfation plate data, Santa Catalina Ranger District, Coronado National Forest	70
19	SO_2 injury between areas 3 and 5, Clifton Ranger District, Apache National Forest	79
20	SO_2 injury between areas 3 and 4, Clifton Ranger District, Apache National Forest	80
21	Sulfation plate data, Clifton Ranger District, Apache National Forest	81
22	Sulfation plate data, Tonto National Monument	93
23	SO_2 injury in area 6, Globe Ranger District, Tonto National Forest	94
24	SO_2 injury in area 10, Globe Ranger District, Tonto National Forest	95
25	SO_2 injury in area 9, W. Bhome Ranch	96
26	Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest	97
27	Schedule for future air pollution monitoring	114

LIST OF FIGURES

Figure	Title	Page
1	Air Pollution Survey-1972.....	4
2	Location of sulfation plates and observation areas, Aztec Ruins National Monument.....	21
3	Location of sulfation plates and observation areas, Mesa Verde National Park.....	22
4	Location of sulfation plates and observation areas, Jicarilla Ranger District, Carson National Forest.....	23
5	Leaf injury caused by the elm leaf beetle which superficially mimics SO_2 injury, Aztec National Monument, Aug. 1972.....	24
6	Needle mottle and fleck of unknown cause, ponderosa pine, Tijeras, New Mexico, Mar. 1973.....	24
7	Location of sulfation plates and observation areas, Cuba Ranger District, Santa Fe National Forest.....	25
8	Location of sulfation plates and observation areas, Chuska Mountains, Navajo Indian Reservation.....	26
9	Location of sulfation plates and observation areas, Patagonia Ranger District, Coronado National Forest; Coronado National Memorial.....	31
10	Location of sulfation plates and observation areas, Douglas Ranger District, Coronado National Forest.....	32
11	Location of observation areas, Lake Mohave, Lake Mead National Recreation Area.....	34
12, 13	Marginal necrosis on elm and cottonwood, probably salt and/or heat injury, Lake Mohave, Oct. 1972.....	35
14	Leaf mottle of undetermined cause, on willow, Lake Mohave, Oct. 1972.....	35
15	Location of sulfation plate and observation areas, Glen Canyon National Recreation Area; Navajo Mountain, Navajo Indian Reservation.....	49

Figure	Title	Page
16, 17	Marginal necrosis on skunkbush and elm, probably drought or heat injury, Glen Canyon National Recreation Area, Jul. 1972	50
18	Chlorosis and marginal necrosis of ash, probably heat injury and iron deficiency, Glen Canyon National Recreation Area, Jul. 1972	50
19	Marginal necrosis on sycamore, probably drought or heat injury, Glen Canyon National Recreation Area, Aug. 1971	50
20	Location of sulfation plates and observation areas, Jacob Lake Ranger District, Kaibab National Forest	51
21	Location of sulfation plates and observation areas, Grand Canyon National Park	52
22	Location of sulfation plates and observation areas, Silver City Ranger District, Gila National Forest	62
23	Drought-caused marginal leaf necrosis on Wright silk tassel, Silver City Ranger District, Sep. 1971	63
24	SO_2 injury to velvetweed, Hurley, New Mexico, Aug. 1972	63
25	Symptoms resembling SO_2 injury to Lombardy poplar, Ft. Bayard, New Mexico, Aug. 1972	63
26	Upper surfaces of elm foliage with necrotic areas of unknown cause, Ft. Bayard, New Mexico, Aug. 1972	63
27	Lower surfaces of elm foliage with necrotic areas of unknown cause, Ft. Bayard, New Mexico, Aug. 1972	64
28	Chlorotic foliage of willow, probably caused by iron deficiency, Silver City Ranger District, Aug. 1972	64
29, 30	Box elder and sumac foliage abnormalities of causes other than SO_2, Silver City Ranger District, Aug. 1972	64
31	Location of sulfation plate stations and observation areas, Mimbres Ranger District and Wilderness Ranger District, Gila National Forest	65

Figure	Title	Page
32	Location of sulfation plates and observation areas, Glenwood Ranger District, Gila National Forest.....	66
33	Location of sulfation plates and observation areas, Santa Catalina Ranger District, Coronado National Forest.....	73
34, 35, 36	SO_2 injury to brickellbush, willow, and cottonwood, Santa Catalina Ranger District, Aug. 1972.....	74
37	Heat or drought injury to ash, Santa Catalina Ranger District, Aug. 1972.....	74
38	Insect-feeding injury to sycamore, probably caused by the western lace bug, Santa Catalina Ranger District, Aug. 1972.....	75
39	Location of sulfation plates and observation areas, Clifton Ranger District, Apache National Forest.....	84
40	SO_2 injury to brickellbush, Morenci, Arizona, Sep. 1971.....	85
41, 42, 43	SO_2 injury to sycamore, cottonwood, and skunkbush, Morenci, Arizona, Aug. 1972.....	85
44, 45	SO_2 injury to willow and sumac, Morenci, Arizona, Aug. 1972.....	86
46, 47	Probable SO_2 injury to mesquite and baccharis, Morenci, Arizona, Aug. 1972.....	86
48, 49, 50	SO_2 injury to brickellbush, skunkbush, and globe mallow, Morenci, Arizona, Aug. 1972.....	87
51	Heat or drought injury to brickellbush, Morenci, Arizona, Aug. 1972.....	87
52, 53, 54	Foliage abnormalities of causes other than SO_2 to sacred datura, hop tree, and maple, Clifton Ranger District, Aug. 1972.....	88
55	Location of sulfation plates and observation areas, Globe Ranger District, Tonto National Forest; Roosevelt Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest; Tonto National Monument.....	105

Figure	Title	Page
56	Location of sulfation plates and observation areas, Tonto Basin Ranger District, Tonto National Forest....	106
57, 58 59	SO_2 injury to sycamore, willow, and brickellbush, Globe Ranger District, Sep. 1972.....	107
60	Symptoms resembling SO_2 injury to cherry, Globe Ranger District, Sep. 1972.....	107
61	Possible symptoms of chronic SO_2 injury to skunkbush, Globe Ranger District, Sep. 1972.....	108
62	SO_2 injury to brickellbush, Globe Ranger District, Sep. 1972.....	108
63, 64	Possible symptoms of chronic SO_2 injury to poison ivy, Globe Ranger District, Sep. 1972.....	108
65, 66, 67, 68	SO_2 injury to black walnut, bee plant, tree tobacco, and cottonwood, Bohme Ranch, Sep. 1972.....	109
69, 70, 71, 72	SO_2 injury to skunkbush, sacred datura, brickellbush, and desert tobacco, Bhome ranch, Sep. 1972.....	110
73	Needle tip burn, pinyon pine, of undetermined cause, Bhome ranch, Sep. 1972.....	111
74	Chlorosis of undetermined cause, of sacred datura, Bhome ranch, Sep. 1972.....	111
75	A black walnut leaf spot of undetermined cause, Roosevelt Ranger District, Sep. 1972.....	111

INTRODUCTION

This report presents the results of an Air Pollution Detection Survey conducted in Arizona and New Mexico by U.S. Forest Service plant pathologists. The survey, begun in July 1970, was intended to obtain information concerning two specific questions. These were:

1. Is sulfur dioxide from existing major sources causing mortality or foliage injury to Southwestern forests?

2. What is the existing foliage condition of trees and associated plants growing in areas where major sources of air pollution are expected in the near future?

Twelve major sources of air pollution are located in, or adjacent to, the Southwestern Region. In addition, four other sources are planned for the near future. All of these major sources are either copper smelters or electrical generating stations. Sulfur dioxide (SO_2) is the major pollutant of concern from the copper smelters. SO_2 and nitrogen oxides (NO_x) are of concern from the electrical power generating stations. Information concerning the location and pollutant output of individual sources is presented in Table 1 and Figure 1.

Impetus was given to the air pollution program in July 1970, when officials of the National Park Service, Southwest Region, requested that we consider what possible effects a proposed electrical generating station near Page, Arizona, might have upon vegetation growing in the Glen Canyon National Recreation Area. While investigating this initial request, it soon became evident that there was little information available concerning the effects of air pollution on forest vegetation elsewhere in the Region. Thus, the initial air pollution investigation was expanded to a Region-wide detection survey. This program was undertaken in order to better answer questions raised by the public, environmental organizations, and government agencies, concerning the effects of air pollution on Southwestern forest vegetation.

In order to increase the efficiency and effectiveness of the field survey, a cooperative study with the University of Arizona[1/] was undertaken in 1972 to determine the symptomatology and relative susceptibility of selected Southwestern forest trees and plants to SO_2. We hope that the present detection techniques will be improved further as new information and equipment become available.

1/ "Screening study of selected native trees and shrubs to sulfur dioxide," conducted by Dr. Roger L. Caldwell, Plant Pathologist, Department of Plant Pathology, University of Arizona, Tucson, Arizona.

Table 1.--Estimates[1/] of pollutant emissions from major sources in New Mexico and Arizona.

Type	Location	Sulfur Oxide Tons/Day	Nitrogen Oxide Tons/Day	Status	Remarks
Smelter	Hurley, New Mexico	650	--	In operation	
Power Plant	Fruitland, New Mexico (Four Corners)	196	143	In operation	
Power Plant	Waterflow, New Mexico	65.5	31.9	1st unit to be completed 6-1-73	2nd unit expected to be built at some future date
Smelter	Hidalgo County, New Mexico	Unknown	--	Construction of smelter not yet begun	
Smelter	Douglas, Arizona	1,440	--	Produce 370 tons Cu/day	No schedule set to reduce emissions
Smelter	Morenci, Arizona	1,320	--	Produce 470 tons Cu/day	Scheduled to decrease to 800 tons SO_2/day 1974
Smelter (2)	Hayden, Arizona	$740/^{508}_{232}$	--	Produce 820 tons Cu/day	Represents totals of 2 smelters located in Hayden. Scheduled to reduce to 630 tons SO_2/day 1974
Smelter	San Manuel, Arizona	1,300	--	Produce 524 tons Cu/day	Scheduled to decrease to 650 tons SO_2/day by 1974

Table 1.--Estimates[1/] of pollutant emissions from major sources in New Mexico and Arizona (cont'd.).

Type	Location	Sulfur Oxide Tons/Day	Nitrogen Oxide Tons/Day	Status	Remarks
Smelter	Inspiration (Globe), Arizona	400	--	Produce 290 tons Cu/day	Scheduled to decrease to 46 tons SO_2/day 2-1-74
Smelter	Ajo, Arizona	430		Produce 203 tons Cu/day	Scheduled to decrease to 20 tons SO_2/day
Power Plant	Page, Arizona Power level 2300 MW (1976)	211	204 (AS NO_2)	Completion schedule - 7-1-74 7-1-76	

1/ New Mexico estimates from the State of New Mexico Environmental Improvement Agency, Air Quality Control Unit, Santa Fe, New Mexico. Arizona estimates from the State of Arizona Department of Health, Division of Air Pollution Control, Phoenix, Arizona.

AIR POLLUTION SURVEY—1972

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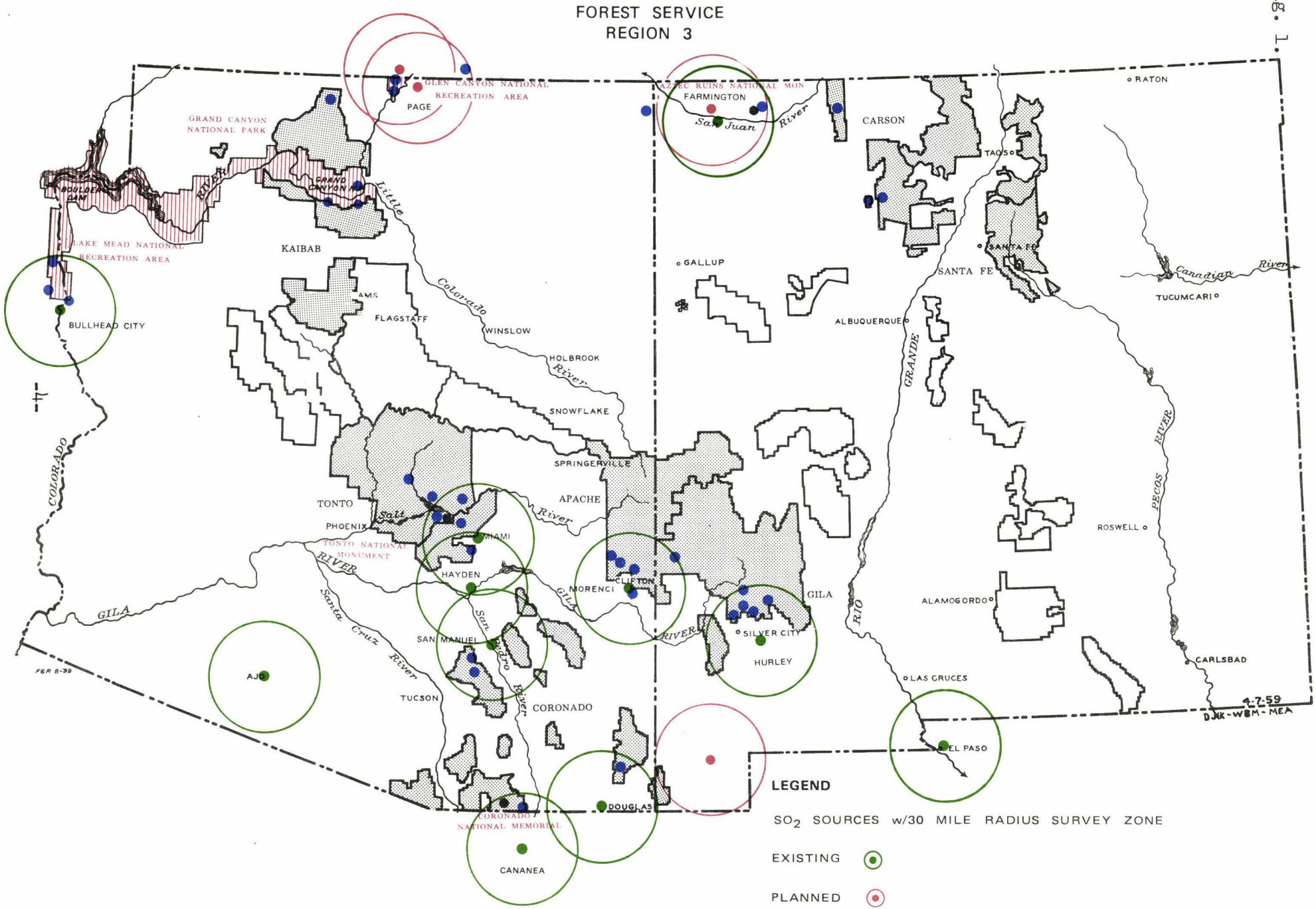
Fig. 1.



LEGEND

SO_2 SOURCES w/30 MILE RADIUS SURVEY ZONE

EXISTING

PLANNED

FOREST VEGETATION OBSERVATION AREAS

METHOD

A detection procedure was needed which would give an indication of the severity of forest plant injury near existing sources of SO_2, and, also, would serve as a basis for background evaluation in areas where a source is expected in the future. To meet this need, forest vegetation observation areas and sulfation plate stations were established during the period of July 1970 to September 1972. The steps in developing the detection procedure were as follows:

1. An emissions inventory was conducted to determine the number, size, and location of major sources of air pollution.

2. Available information was collected on pollutant distribution patterns for each area.

3. Forest areas which fall within both the normal pollutant distribution pattern and a 30-mile radius from the source were located. The 30-mile limit was thought to be the maximum distance that injury might occur to Southwestern forest vegetation, and was based upon distances from the source of reported field crop injury.

4. Sensitive observation areas were selected and sulfation plate stations were established in the forest areas described above. The observation areas were variable in size, ranging from several chains of roadside ditch to approximately 30 acres. Considerations for establishing these areas included:

a. A variety of trees and associated plants growing in the area. One phase in evaluating possible air pollution injury to plants is to determine if similar injury has occurred to a variety of plant species (1).

b. Adequate soil moisture and high humidity. Plants growing in areas with adequate soil moisture and high humidity are more susceptible to SO_2 injury than plants growing under moisture stress (1).

Sensitive observation areas were selected so that some conclusions about the effect of SO_2 on plants throughout a particular area could be made, based on the effect of air pollution on plants in these observation areas. For example, if no injury occurred in the sensitive areas, then one would not expect to find injury in adjacent, less sensitive areas.

Sulfation plates were used to determine if SO_2 and other sulfur compounds were reaching the observation areas. In addition, the relationship between sulfation rate and plant injury was investigated. The sulfation plates were exposed for approximately 30 days, during which time sulfur compounds react with the lead dioxide in the plate. The product of these reactants is then measured and expressed in micrograms of $SO_3/cm^2/day$ (6). This is commonly called the sulfation rate. Thus, areas which have high levels of SO_2 in the air would have high sulfation rates.

5. Examine vegetation on the observation areas. The foliage of broad-leaved trees and plants was examined for interveinal bleaching or browning. The foliage of conifers was examined for tipburn or banding. These symptoms are typical of acute SO_2 injury (1). In addition, leaf and needle abnormalities which resembled acute SO_2 injury were noted for future reference. Neither chronic injury nor the so-called "invisible" injury were evaluated in this survey.

Due to the extensive nature of the survey, it was possible to examine each observation area only once during the growing season. Therefore, in order to improve the chances for examining the areas during maximum symptom development, the greater part of the survey was conducted during the months of July to September. Symptom development should be greatest during this time because it is the period of greatest rainfall, and because foliage had been exposed for much of the growing season.

In areas where foliage injury was noted, two estimates of injury were made for each plant species. The first was an estimate of the proportion of leaves with SO_2 symptoms on injured plants. The second was an estimate of the proportion of plants which were injured. Both estimates were based on the following injury classes: 0 = none; 1 = 1-33%; 2 = 34-66%; 3 = 67-100% injury. Thus, if an estimated 20% of the leaves on injured plants had symptoms of injury, and an estimated 60% of the plants had symptoms of injury, that particular species would have a rating of "1/2".

Color photographs were taken of injured foliage to help document the symptomatology of observed air pollution injury. To do this, a Polaroid CU-5 Close-up Land Camera with Polacolor Land Film Type 108[2/] was used. This camera system has the advantage of producing color prints in the field, thereby insuring the investigator that the desired picture was obtained. Several drawbacks to the use of this equipment were encountered. These include: bulkiness and weight of the camera, sensitivity of the film to excessive heat, and the large amount of trash generated when developing the film.

2/ The identification of commercial products in this report is solely for the information of the reader and is not an endorsement of the product.

RESULTS

Evaluation results for the 24 survey areas included in the survey are presented in this section. Individual areas are grouped and discussed according to the air pollution source(s) which may affect them (Table 2). In addition, sulfation plate reliability is discussed.

Group I.--Aztec Ruins National Monument; Chuska Mountains, Navajo Indian Reservation; Jicarilla Ranger District, Carson National Forest; Cuba Ranger District, Santa Fe National Forest; Mesa Verde National Park

Aztec Ruins National Monument

The Aztec Ruins National Monument is located approximately 25 miles from the Four Corners Electrical Power Generating Station (Fig. 2). This area was examined in August 1971 and in August 1972 for symptoms of acute air pollution injury. No symptoms of injury were found on any of the following trees and plants:

Ash (*Fraxinus* spp.)
Cottonwood (*Populus* spp.)
Elm (*Ulmus* spp.)
Ribes (*Ribes* spp.)
Skunkbush (*Rhus trilobata*)

A moderate to heavy infestation of elm trees by the elm leaf beetle, *Pyrrhalta luteola*, was noted in the 1971 survey report (7). This infestation has continued and was noted again during the 1972 survey. Leaf injury by this insect can superficially resemble acute SO_2 injury (Fig. 5).

Sulfation plate data for the period September 1970 to October 1971 are presented in Table 3. This sulfation plate station, located near the Monument headquarters, was discontinued in November 1971. Recorded sulfation rates are no higher than rates recorded in areas far from known sources of SO_2 pollution.

Mesa Verde National Park

The southern boundary of Mesa Verde National Park is located approximately 30 miles from the Four Corners Electrical Power Generating Station. Forest vegetation on selected observation areas was examined for symptoms of air pollution injury in August 1971 and

Table 2.--Pollution sources and survey area groups.

Source Existing and Future	Location of Survey Areas
	Group I
San Juan Power Plant and Four Corners Power Plant, near Farmington, New Mexico	*Mesa Verde National Park, Colorado Aztec Ruins National Monument, Aztec, New Mexico Chuska Mountains, Navajo Indian Reservation, New Mexico and Arizona Jicarilla Ranger District, Carson National Forest, New Mexico Cuba Ranger District, Santa Fe National Forest, New Mexico
	Group II
Phelps Dodge Copper Smelter, Douglas, Arizona Anaconda Copper Smelter, Cananea, Mexico	Coronado National Memorial, Arizona Douglas Ranger District, Coronado National Forest, Arizona Patagonia Ranger District, Coronado National Forest, Arizona
	Group III
Mohave Power Plant, near Bullhead City, Arizona	**Lake Mohave Ranger District, Lake Mead National Recreation Area, Arizona
	Group IV
Kaiparowits Power Plant and Navajo Power Plant, near Page, Arizona	**Glen Canyon National Recreation Area, Arizona Navajo Mountain, Navajo Indian Reservation, Arizona North and South Rim, Grand Canyon, Arizona Jacob Lake Ranger District, Kaibab National Forest, Arizona

*Cooperative effort between Forest Service, Region 3, Albuquerque, New Mexico, and Forest Service, Region 2, Denver, Colorado.
**Cooperative effort between Forest Service, Region 3, Albuquerque, New Mexico, and Forest Service, Region 4, Ogden, Utah.

Table 2.--Pollution sources and survey area groups (cont'd.).

Source Existing and Future	Location of Survey Areas
	Group V
Kennecott Copper Smelter, Hurley, New Mexico	Silver City Ranger District, Gila National Forest, New Mexico Mimbres Ranger District, Gila National Forest, New Mexico Wilderness Ranger District, Gila National Forest, New Mexico Glenwood Ranger District, Gila National Forest, New Mexico
	Group VI
Magma Copper Smelter, San Manuel, Arizona	Santa Catalina Ranger, District, Coronado National Forest, Arizona
	Group VII
Phelps Dodge Copper Smelter, Morenci, Arizona	Clifton Ranger District, Apache National Forest, Arizona
	Group VIII
Inspiration Copper Smelter, Miami, Arizona	Tonto National Monument, Arizona Sierra Ancha Experimental Forest,Arizona Globe Ranger District, Tonto National Forest, Arizona Roosevelt Ranger District, Tonto National Forest, Arizona Tonto Basin Ranger District, Tonto National Forest, Arizona

August 1972.[3/] The location of the observation areas and sulfation plate stations is noted in Figure 3. No symptoms of injury were found during either survey. The following tree and plant species were examined:

Aspen (Populus tremuloides)
Box elder (Acer negundo)
Douglas-fir (Pseudotsuga menziesii)
Gambel oak (Quercus gambelii)
Juniper (Juniperus spp.)
Mountain mahogany (Cercocarpus spp.)
Pinyon pine (Pinus edulis)
Poison ivy (Toxicodendron radicans)
Ponderosa pine (Pinus ponderosa)
Serviceberry (Amelanchier spp.)
Skunkbush (Rhus trilobata)
Wild cherry (Prunus spp.)
Wild currant (Ribes spp.)
Wild rose (Rosa spp.)

Some foliage injury to wild cherry by lace bugs (family Tingidae), rust on ribes, and insect feeding on Gambel oak were discussed in the 1971 survey report (7). This year, several dead and declining pinyon pine trees were examined. These trees were infested by Verticicladiella wagenerii, a root disease of pines.

Sulfation plate data for the period September 1970 to October 1971 are listed in Table 4. These sulfation plate stations were discontinued in November 1971. Recorded sulfation rates were no higher than rates recorded in areas far from known sources of SO_2 pollution.

Jicarilla Ranger District, Carson National Forest

The Jicarilla Ranger District is located approximately 60 miles from the Four Corners Power Station. Forest vegetation on selected observation areas was examined in August 1971 and August 1972 for symptoms of air pollution injury. The location of the observation areas and sulfation plate stations is noted on Figure 4. No symptoms of injury were noted during either survey. The following tree and plant species were examined:

Aspen (Populus tremuloides)
Cocklebur (Xanthium strumarium)
Gambel oak (Quercus gambelii)

3/ In 1972, examined jointly by R. C. Loomis, Plant Pathologist, Forest Service, Region 3, and D. H. Brown, Plant Pathologist, Forest Service, Region 2.

Juniper (Juniperus spp.)
Lupine (Lupinus spp.)
Mountain mahogany (Cercocarpus spp.)
Pinyon pine (Pinus edulis)
Ponderosa pine (Pinus ponderosa)
Rabbit brush (Chrysothamnus spp.)
Sagebrush (Artemisia spp.)
Skunkbush (Rhus trilobata)
Snowberry (Symphoricarpos spp.)
Wild cherry (Prunus spp.)
Wild rose (Rosa spp.)
Willow (Salix spp.)

A needle fleck of unknown cause on older ponderosa pine foliage (Fig. 6) and aspen decline of unknown cause in area 3 were discussed in the 1971 survey report (8). No additional findings were made concerning plant condition in 1972.

Sulfation plate data for the period September 1970 to October 1971 are presented in Table 5. These low sulfation rates are similar to those recorded in other areas far from known sources of SO_2 air pollution.

Cuba Ranger District, Santa Fe National Forest

The observation areas and sulfation plate stations on the Cuba Ranger District are located approximately 100 miles from the Four Corners Power Station. The location of the observation areas and sulfation plate stations are noted on Figure 7. These areas were examined in August 1971 and August 1972. No symptoms of air pollution injury were found in any observation area during either the 1971 or 1972 survey. The following tree and plant species were examined:

Douglas-fir (Pseudotsuga menziesii)
Elderberry (Sambucus glauca)
Engelmann spruce (Picea engelmannii)
Gambel oak (Quercus gambelii)
Hawthorn (Crataegus spp.)
Juniper (Juniperus spp.)
Limber pine (Pinus flexilis)
Lupine (Lupinus spp.)
Mountain mahogany (Cercocarpus spp.)
New Mexican locust (Robinia neomexicana)
Pinyon pine (Pinus edulis)
Ponderosa pine (Pinus ponderosa)
Raspberry (Rubus spp.)

Rocky Mountain maple (Acer glabrum)
Snowberry (Symphoricarpos spp.)
Sunflower (Helianthus annus)
White fir (Abies concolor)
Wild currant (Ribes spp.)
Wild rose (Rosa spp.)
Willow (Salix spp.)

A needle mottle or fleck was noted on older ponderosa pine needles (Fig. 6), but only rarely noted on current year's needles. A decline of Douglas-fir trees was noted in area 6 in the 1971 survey report (8). Dwarf mistletoe (Arceuthobium douglasii) is probably a contributing factor.

During the 1972 survey, hail injury was noted in area 7.

Sulfation plate data for the period September 1970 to October 1971 are listed in Table 6. These sulfation plate stations were discontinued in November 1971. These low rates are similar to those recorded in areas far from known sources of SO_2 air pollution.

Chuska Mountains, Navajo Indian Reservation

The observation areas, located in and near the Chuska Mountains, are all at least 40 miles from the Four Corners Power Station. The location of these observation areas and sulfation plate stations is noted on Figure 8. No symptoms of acute air pollution injury were noted in either the August 1971 or June 1972 survey. Plant condition was discussed in the 1971 report (9).

The following plant species were examined for evidence of acute SO_2 injury:

Aspen (Populus tremuloides)
Ash (Fraxinus velutina)
Birch (Betula occidentalis)
Blue spruce (Picea pungens)
Box elder (Acer negundo)
Cottonwood (Populus spp.)
Douglas-fir (Pseudotsuga menziesii)
Ferns (Pteridium spp.)
Gambel oak (Quercus gambelii)
Juniper (Juniperus spp.)
Pinyon pine (Pinus edulis)
Ponderosa pine (Pinus ponderosa)
Serviceberry (Amelanchier spp.)
Snowberry (Symphoricarpos spp.)
Wild currant (Ribes spp.)
Wild rose (Rosa spp.)

Sulfation plate data for the period July 1971 to September 1972 are listed in Table 7. These sulfation plate stations were discontinued in October 1972. These low sulfation rates are comparable to rates recorded in areas far from known sources of SO_2 pollution.

Discussion

To date, no symptoms of acute SO_2 injury have been noted on trees and associated forest vegetation examined on the survey observation areas in the vicinity of the Four Corners and San Juan Electrical Power Generating Stations. A study, prepared by the U.S. Department of Health, Education and Welfare for the Four Corners Station (23), suggests that plant damage is most likely to occur within a radius of 10 miles of the station, but that there is a possibility of detectable damage to sensitive vegetation on the western edges of the Carson and Santa Fe National Forests. These two National Forests are more than 60 and 80 miles, respectively, from the Four Corners Power Station. A study, by the University of Utah (22), suggests that SO_2 and NO_x emitted from the Four Corners Plant during 1971 did not cause acute injury or suppress the growth of plants growing in the vicinity of the station. The study further notes that the four units of the San Juan Plant, with no SO_2 and NO_x controls, will emit approximately the same amount of these pollutants as the present Four Corners Plant; and, because the terrain and vegetation around the two plant sites are similar, it is unlikely that pollutants from the four San Juan units will have any effect on vegetation. The study also concludes that there is little reason to think that the effluents from the two plants will combine and cause ground level concentrations high enough to cause plant injury.

During the course of our Region-wide air pollution survey, symptoms of acute SO_2 injury to forest plants have not been observed at distances greater than 7 miles from sources of SO_2 air pollution. These observations were made in the vicinity of air pollution sources whose SO_2 emissions are greater than the expected combined total of emissions from the Four Corners Station and the nearby San Juan Station, which is now under construction. Therefore, based on previous studies, our survey experience, and sulfation plate data, we do not expect to find symptoms of acute SO_2 injury to vegetation on the Carson National Forest, Santa Fe National Forest, Navajo Indian Reservation, Aztec Ruins National Monument, and Mesa Verde National Park.

Table 3.--Sulfation plate data, Aztec Ruins National Monument.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Sep. 1970	21	2.2
Oct.	31	1.5
Nov.	29	** <Detectable minimum
Dec.	31	1.9
Jan. 1971	34	<Detectable minimum
Feb.	25	<Detectable minimum
Mar.	31	1.7
Apr.	30	2.9
May	31	<Detectable minimum
Jun.	30	1.3
Jul.	31	< Detectable minimum
Aug.	31	1.5
Sep.	30	<Detectable minimum
Oct.	31	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Sep. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971 - 1.3

Table 4.--Sulfation plate data, Mesa Verde National Park.

Area 1

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Sep. 1970	22	5.3
Oct.	32	1.1
Nov.	29	1.6
Dec.	34	** <Detectable minimum
Jan. 1971	25	3.7
Feb.	31	<Detectable minimum
Mar.	31	4.1
Apr.	29	3.0
May	31	<Detectable minimum
Jun.	34	<Detectable minimum
Jul.	28	<Detectable minimum
Aug.	--	--
Sep.	29	<Detectable minimum
Oct.	30	<Detectable minimum

Area 2

Sep. 1970	22	<Detectable minimum
Oct.	32	<Detectable minimum
Nov.	29	<Detectable minimum
Dec. & Jan. 1971	59	<Detectable minimum
Feb. & Mar.	59	1.5
Apr.	29	3.6
May	31	<Detectable minimum
Jun.	34	<Detectable minimum
Jul.	28	<Detectable minimum
Aug.	32	2.7
Sep.	29	<Detectable minimum
Oct.	30	<Detectable minimum

Table 4.--Sulfation plate data, Mesa Verde National Park (cont'd.).

Area 3

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Sep. 1970	22	2.9
Oct.	32	** <Detectable minimum
Nov.	--	--
Dec.	34	<Detectable minimum
Jan. 1971	25	<Detectable minimum
Feb.	31	<Detectable minimum
Mar.	31	1.7
Apr.	29	3.0
May	31	<Detectable minimum
Jun.	34	<Detectable minimum
Jul.	27	<Detectable minimum
Aug.	32	4.1
Sep.	30	<Detectable minimum
Oct.	29	<Detectable minimum

Area 4

Sep. 1970	22	2.9
Oct.	32	1.5
Nov.	29	<Detectable minimum
Dec.	34	<Detectable minimum
Jan. 1971	25	2.3
Feb.	31	<Detectable minimum
Mar.	31	1.7
Apr.	29	3.0
May	31	<Detectable minimum
Jun.	34	<Detectable minimum
Jul.	27	<Detectable minimum
Aug.	33	2.6
Sep.	30	<Detectable minimum
Oct.	29	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Sep. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971 - 1.3

Table 5.--Sulfation plate data, Jicarilla Ranger District, Carson National Forest.

Area 1

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Sep. 1970	18	** <Detectable minimum
Oct.	46	<Detectable minimum
Nov.	18	<Detectable minimum
Dec.	27	<Detectable minimum
Jan. 1971	37	<Detectable minimum
Feb.	20	2.9
Mar.	34	3.1
Apr.	32	1.6
May	33	1.2
Jun.	26	<Detectable minimum
Jul.	29	3.8
Aug.	31	<Detectable minimum
Sep.	31	<Detectable minimum
Oct.	36	1.1

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Sep. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971 - 1.3

Table 6.--Sulfation plate data, Cuba Ranger District, Santa Fe National Forest.

Area 1

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Aug. 1970	31	1.9
Sep.	31	** <Detectable minimum
Oct.	31	<Detectable minimum
Nov.	32	<Detectable minimum
Dec.	44	<Detectable minimum
Jan. 1971	26	4.9
Feb.	28	<Detectable minimum
Mar.	32	2.7
Apr.	28	3.7
May	32	<Detectable minimum
Jun.	30	Detectable minimum
Jul.	32	1.4
Aug.	29	<Detectable minimum
Sep.	34	<Detectable minimum
Oct.	28	<Detectable minimum

Area 2

Aug. 1970	31	2.2
Sep.	31	<Detectable minimum
Oct.	31	<Detectable minimum
Nov.	32	2.5
Dec.	44	1.7
Jan. 1971	26	2.2
Feb.	28	<Detectable minimum
Mar.	32	2.7
Apr.	28	1.9
May	32	1.8
Jun.	30	<Detectable minimum
Jul.	32	<Detectable minimum
Aug.	29	1.6
Sep.	34	<Detectable minimum
Oct.	28	<Detectable minimum

Table 6.--Sulfation plate data, Cuba Ranger District, Santa Fe National Forest (cont'd.).

Area 3

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Aug. 1970	31	** <Detectable minimum
Sep.	31	<Detectable minimum
Oct.	31	<Detectable minimum
Nov.	32	<Detectable minimum
Dec.	44	<Detectable minimum
Jan. 1971	26	2.2
Feb.	28	3.3
Mar.	32	1.6
Apr.	28	3.1
May	32	<Detectable minimum
Jun.	30	<Detectable minimum
Jul.	32	<Detectable minimum
Aug.	29	<Detectable minimum
Sep.	34	<Detectable minimum
Oct.	28	<Detectable minimum

Area 4

Aug. 1970	30	2.1
Sep.	31	<Detectable minimum
Oct.	31	<Detectable minimum
Nov.	32	<Detectable minimum
Dec.-Jan. 1971	69	<Detectable minimum
Feb.	28	<Detectable minimum
Mar.	32	2.7
Apr.	28	3.1
May	32	<Detectable minimum
Jun.	30	<Detectable minimum
Jul.	32	3.4
Aug.	30	<Detectable minimum
Sep.	33	<Detectable minimum
Oct.	28	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Aug. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971 - 1.3

Table 7.--Sulfation plate data, Chuska Mountains, Navajo Indian Reservation.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Area 1		
Jul. 1971	37	** <Detectable minimum
Aug.	27	1.7
Sep.	31	<Detectable minimum
Oct.	32	<Detectable minimum
Nov.	36	<Detectable minimum
Dec.	30	<Detectable minimum
Jan. 1972	26	<Detectable minimum
Feb.	--	--
Mar.	31	<Detectable minimum
Apr.	34	<Detectable minimum
May	27	4.3
Jun.	31	<Detectable minimum
Jul.	30	<Detectable minimum
Aug.	31	<Detectable minimum
Sep.	29	2.0
Area 2		
Jul. 1971	37	<Detectable minimum
Aug.	27	4.1
Sep.	31	<Detectable minimum
Oct.	32	1.3
Nov.	36	<Detectable minimum
Dec.	30	<Detectable minimum
Jan. 1972	26	<Detectable minimum
Feb.	27	<Detectable minimum
Mar.	31	<Detectable minimum
Apr.	34	<Detectable minimum
May	27	<Detectable minimum
Jun.	31	<Detectable minimum
Jul.	30	<Detectable minimum
Aug.	31	2.0
Sep.	29	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Jul. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972-Sep. 1972 - 1.3

Fig. 2.--Location of sulfation plates and observation areas, Aztec Ruins National Monument.

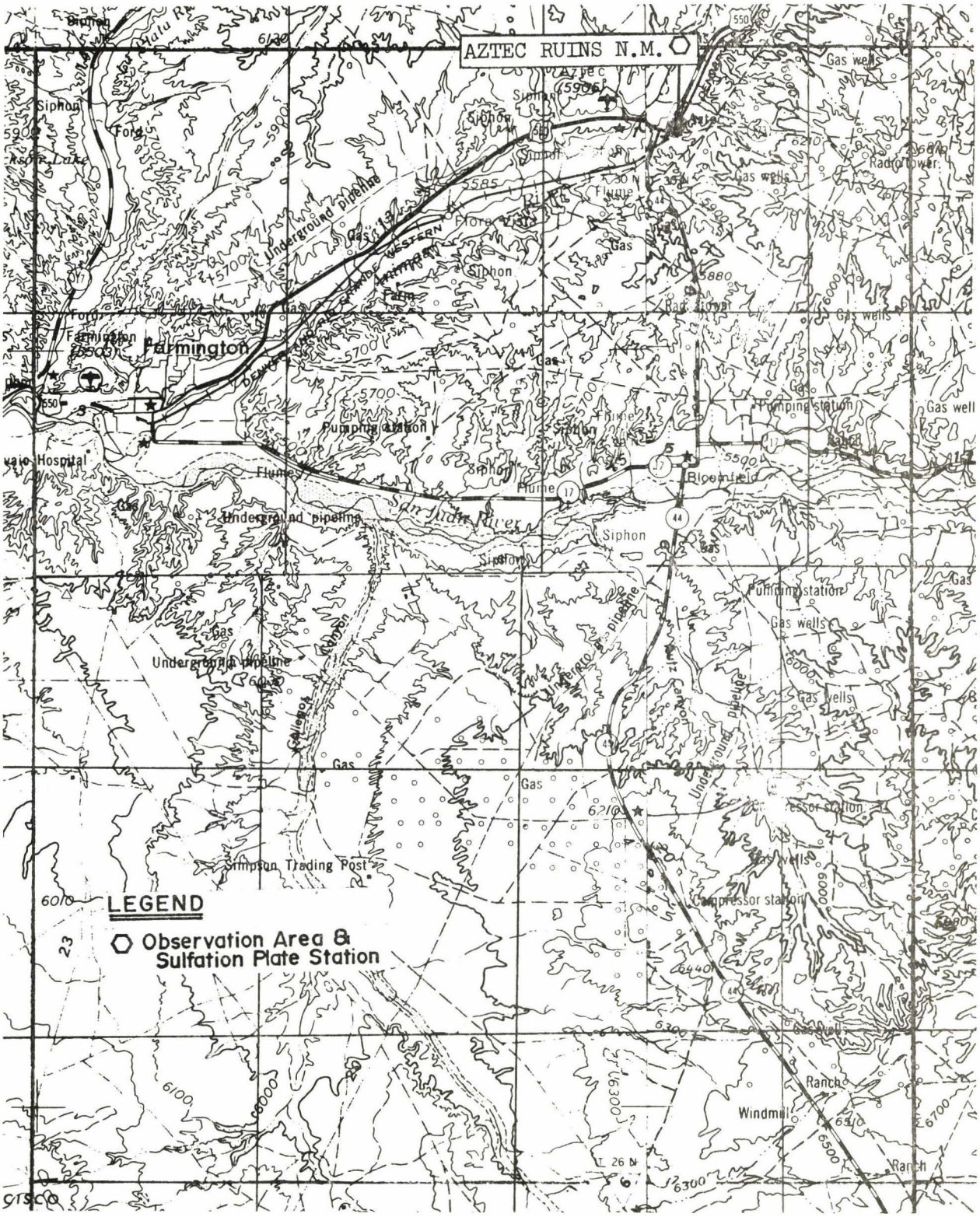


Fig. 3.--Location of sulfation plates and observation areas, Mesa Verde National Park.

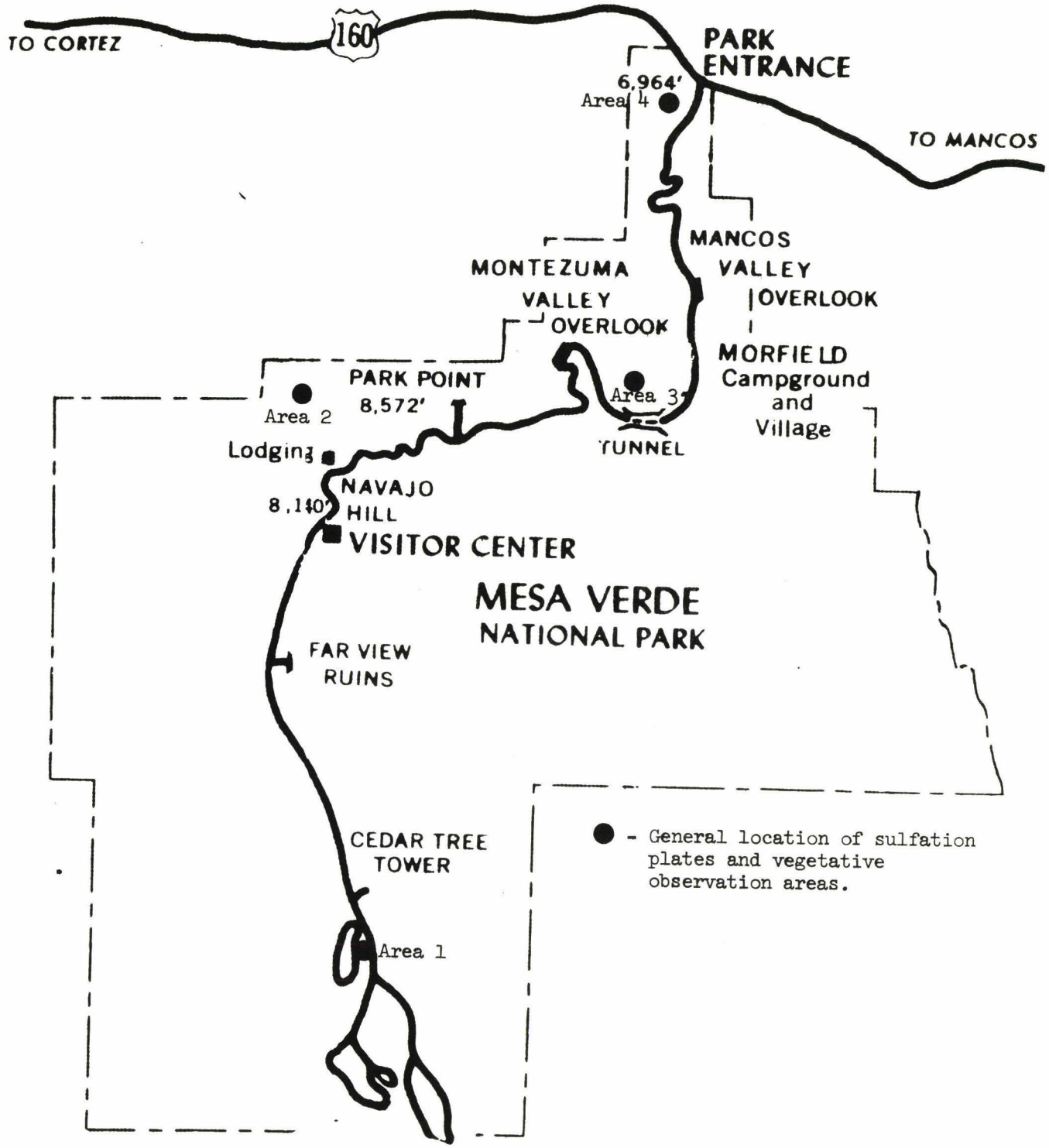
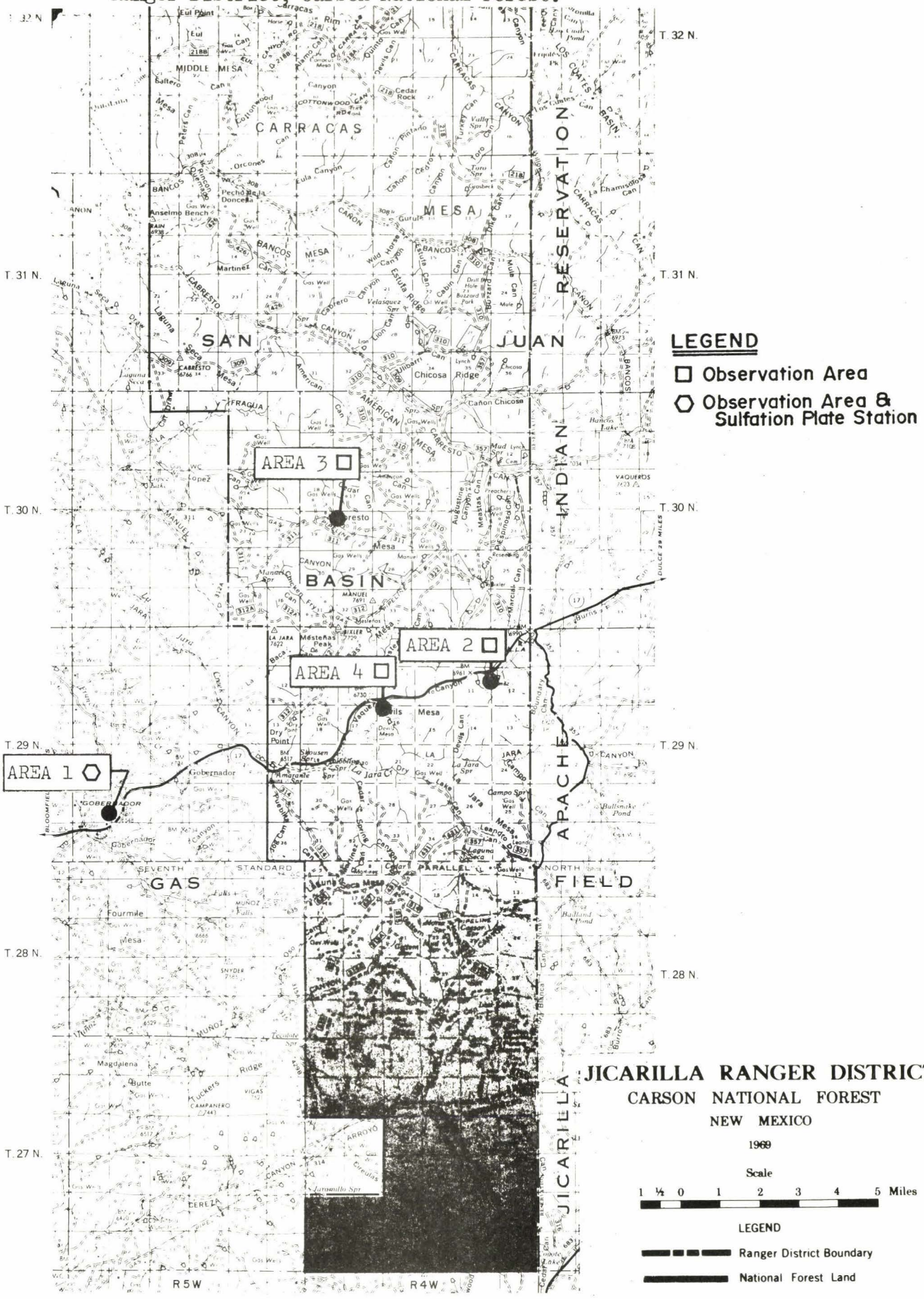


Fig. 4.--Location of sulfation plates and observation areas, Jicarilla Ranger District, Carson National Forest.



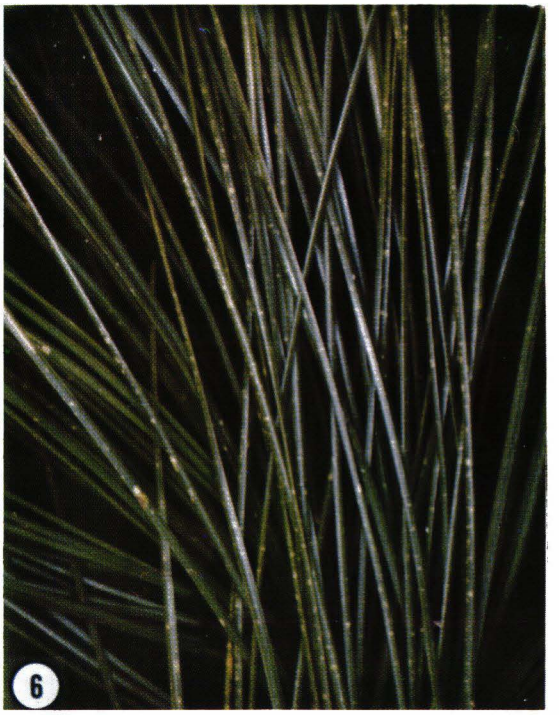


Fig. 5. – Leaf injury caused by the elm leaf beetle which superficially mimics SO_2 injury, Aztec National Monument, Aug. 1972.

Fig. 6. – Needle mottle and fleck of unknown cause, ponderosa pine, Tijeras, New Mexico, Mar. 1973.

Fig. 7.--Location of sulfation plates and observation areas, Cuba Ranger District, Santa Fe National Forest.

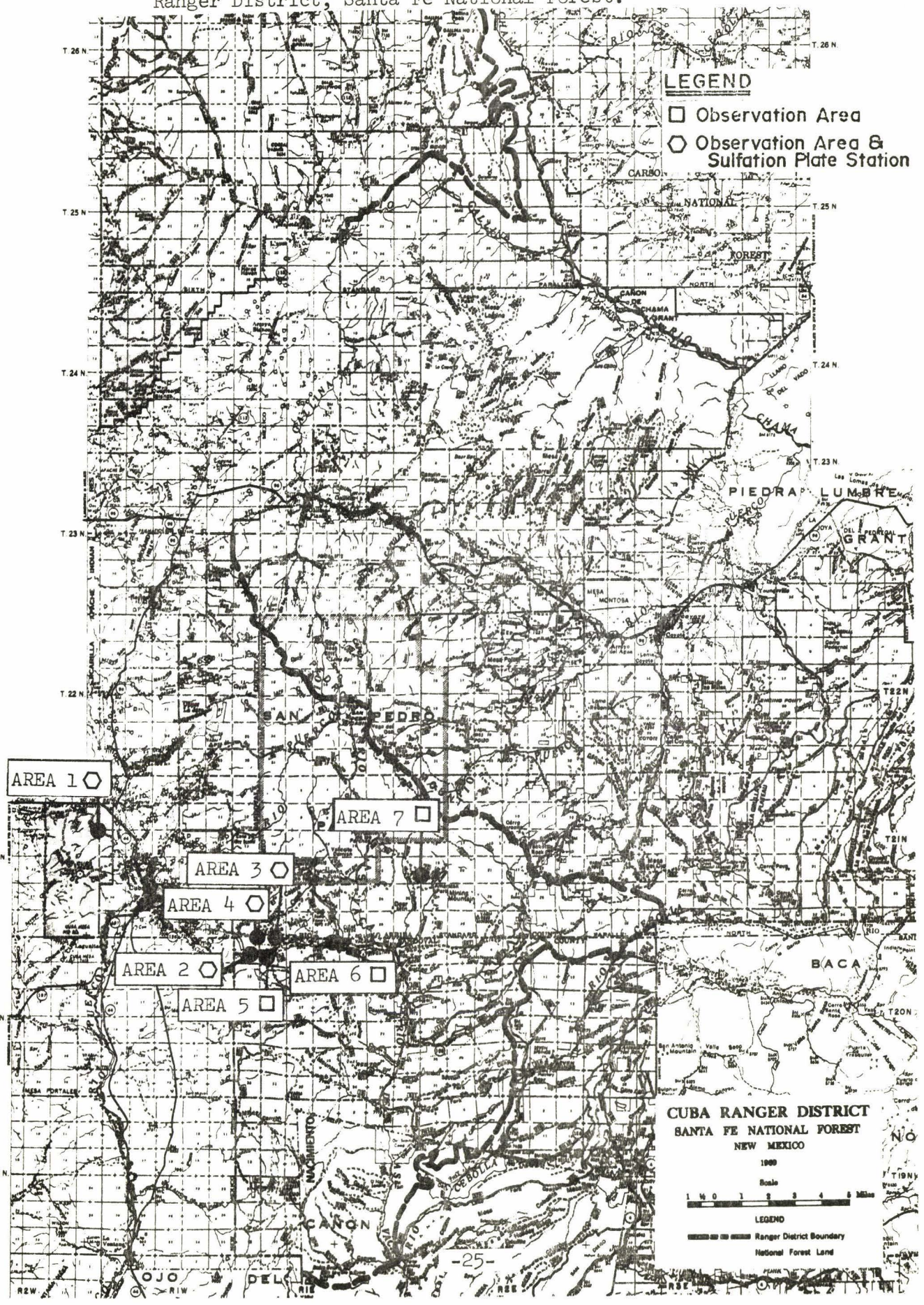
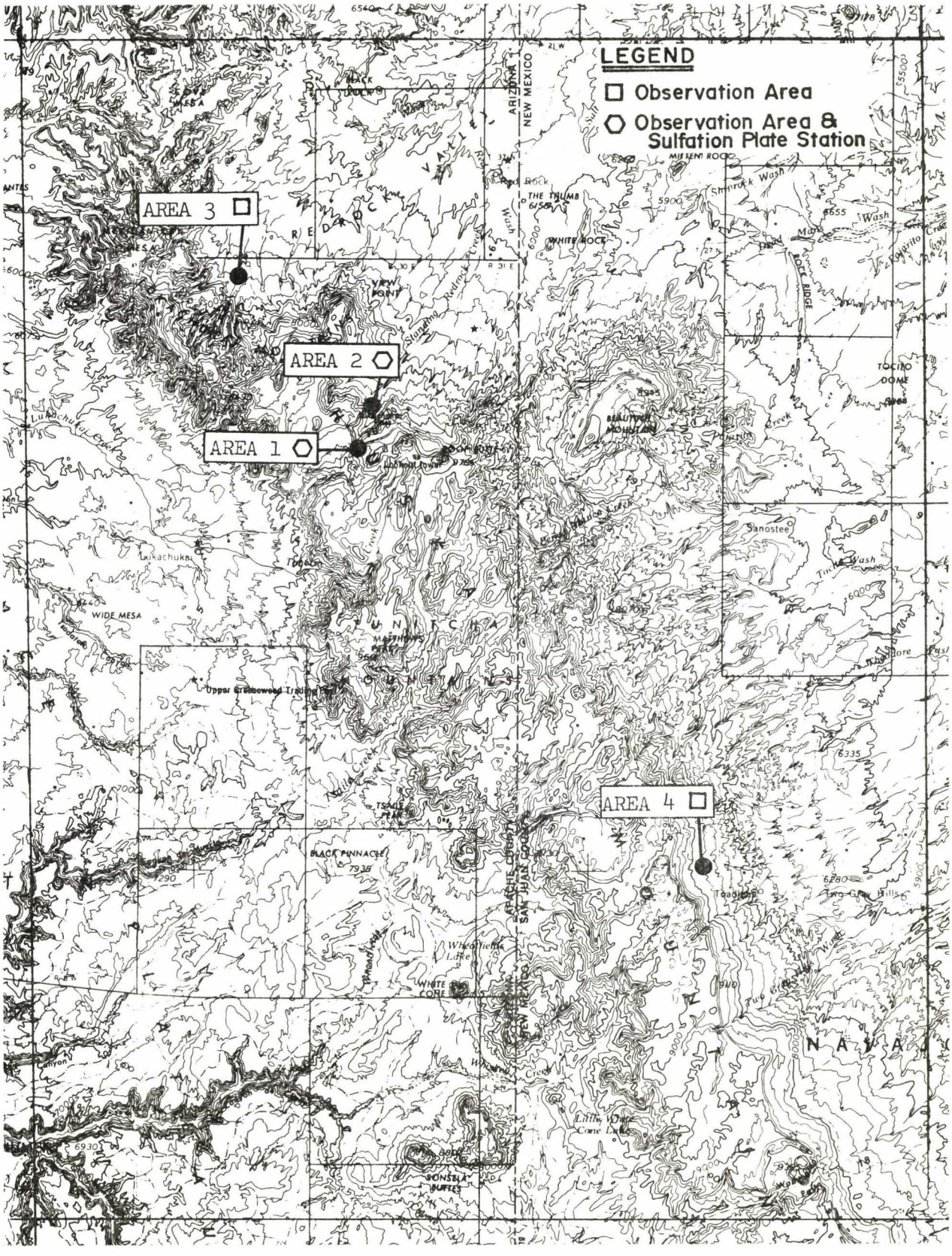


Fig. 8.--Location of sulfation plates and observation areas, Chuska Mountains, Navajo Indian Reservation.



Group II.--Coronado National Memorial; Douglas Ranger District, Coronado National Forest; Patagonia Ranger District, Coronado National Forest

Coronado National Memorial; Patagonia Ranger District, Coronado National Forest

The observation areas on the Coronado National Memorial and on the Patagonia Ranger District were examined in September 1971 and September 1972. These areas (Fig. 9) are approximately 40 miles from the copper smelter at Douglas, Arizona, and approximately 25 miles from the copper smelter at Cananea, Mexico. No symptoms of acute SO_2 injury were noted in any observation area either during the 1971 survey or the 1972 survey. Some observations about general tree and plant condition are presented in the 1971 survey reports (10, 11).

The following plant species were examined for symptoms of acute SO_2 injury:

Arizona sycamore (Platanus wrightii)
Arizona walnut (Juglans major)
Brickelbush (Brickellia spp.)
Cottonwood (Populus spp.)
Golden crownbeard (Verbesina encelioides)
Grape (Vitis spp.)
Juniper (Juniperus spp.)
Mexican pinyon (Pinus cembroides)
New Mexican locust (Robinia neomexicana)
Oak (Quercus spp.)
Poison ivy (Toxicodendron radicans)
Sacred datura (Datura meteloides)
Skunkbush (Rhus trilobata)

Sulfation plate data collected at the Coronado National Memorial for the period August 1971 to October 1972 is presented in Table 8. This station was discontinued in November 1972.

Douglas Ranger District, Coronado National Forest

The observation areas on the Douglas Ranger District are located approximately 35 miles from the copper smelter at Douglas, Arizona. These areas were examined in September 1971 and September 1972. The location of the observation areas and sulfation plate stations are noted on Figure 10. No symptoms of air pollution injury were found

during either the 1971 and 1972 survey. The following tree and plant species were examined for symptoms of acute SO_2 injury:

Apache pine (Pinus latifolia)
Arizona cypress (Cupressus arizonica)
Arizona sycamore (Platanus wrightii)
Arizona walnut (Juglans major)
Ash (Fraxinus spp.)
Bindweed (Convolvulus spp.)
Brickelbush (Brickellia spp.)
Chihuahua pine (Pinus leiophylla var. chihuahuana)
Cockelbur (Xanthium strumarium)
Douglas-fir (Pseudotsuga menziesii)
Globe mallow (Sphaeralcea spp.)
Golden crownbeard (Verbesina encelioides)
Lamb's-quarter (Chenopodium album)
Lupine (Lupinus spp.)
Nightshade (Solanum spp.)
Oak (Quercus spp.)
Plantain (Plantago spp.)
Ponderosa pine (Pinus ponderosa)
Willow (Salix spp.)

A needle fleck of unknown cause on older ponderosa pine foliage (Fig. 6) and drought-induced decline and mortality of Chihuahua pine were discussed in the 1971 survey report (11). In 1972, less mortality of Chihuahua pine was noticed, and the needle fleck was also noted on both current year's and older needles of Apache and Chihuahua pine.

Sulfation plate data for the period August 1971 to October 1972 are presented in Table 9. These sulfation plate stations were discontinued in November 1972. These low sulfation rates are comparable to those recorded in areas far from known sources of SO_2 air pollution.

Discussion

No symptoms of acute SO_2 injury have been noted in any observation area in the vicinity of the copper smelters at Douglas, Arizona, and Cananea, Mexico. In addition, monthly sulfation rates have been very low in all areas.

During the course of our Region-wide air pollution surveys, symptoms of acute SO_2 injury have not been observed more than 7 miles from the source. Therefore, based on previous survey experience and on our sulfation plate date, we do not expect to find symptoms of acute SO_2 injury on the Coronado National Monument, the Douglas Ranger District, and the Patagonia Ranger District.

Table 8.--Sulfation plate data, Coronado National Memorial.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Aug. 1971	33	4.9
Sep.	28	1.4
Oct.	33	** <Detectable minimum
Nov.	34	<Detectable mimimum
Dec.	29	<Detectable minimum
Jan. 1972	31	<Detectable minimum
Feb.	29	2.8
Mar.	34	2.2
Apr.	27	2.8
May	31	4.8
Jun.	30	<Detectable minimum
Jul.	--	--
Aug.	31	<Detectable minimum
Sep.	30	<Detectable minimum
Oct.	31	1.9

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)

Aug. 1971	- 1.0
Sep. 1971	- 0.8
Oct. 1971-May 1972	- 1.3
Jun. 1972-Jul. 1972	- 1.9
Aug. 1972-Oct. 1972	- 1.3

Table 9.--Sulfation plate data, Douglas Ranger District, Coronado National Forest.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Area 3		
Aug. 1971	36	1.3
Sep.	26	** <Detectable minimum
Oct.	30	<Detectable minimum
Nov.	33	<Detectable minimum
Dec.	42	<Detectable minimum
Jan. 1972	17	<Detectable minimum
Feb.	35	<Detectable minimum
Mar.	24	<Detectable minimum
Apr.	32	<Detectable minimum
May	33	<Detectable minimum
Jun.	26	<Detectable minimum
Jul.	32	<Detectable minimum
Aug.	33	<Detectable minimum
Sep.	34	2.9
Oct.	28	2.1
Area 4		
Aug. 1971	36	<Detectable minimum
Sep.	26	<Detectable minimum
Oct.	30	<Detectable minimum
Nov.	33	<Detectable minimum
Dec.	42	<Detectable minimum
Jan. 1972	17	<Detectable minimum
Feb.	35	<Detectable minimum
Mar.	24	<Detectable minimum
Apr.	32	<Detectable minimum
May	33	<Detectable minimum
Jun.	26	<Detectable minimum
Jul.	30	<Detectable minimum
Aug.	35	1.8
Sep.	34	<Detectable minimum
Oct.	28	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)

Aug. 1971	- 1.0
Sep. 1971	- 0.8
Oct. 1971-May 1972	- 1.3
Jun. 1972-Jul. 1972	- 1.9
Aug. 1972-Oct. 1972	- 1.3

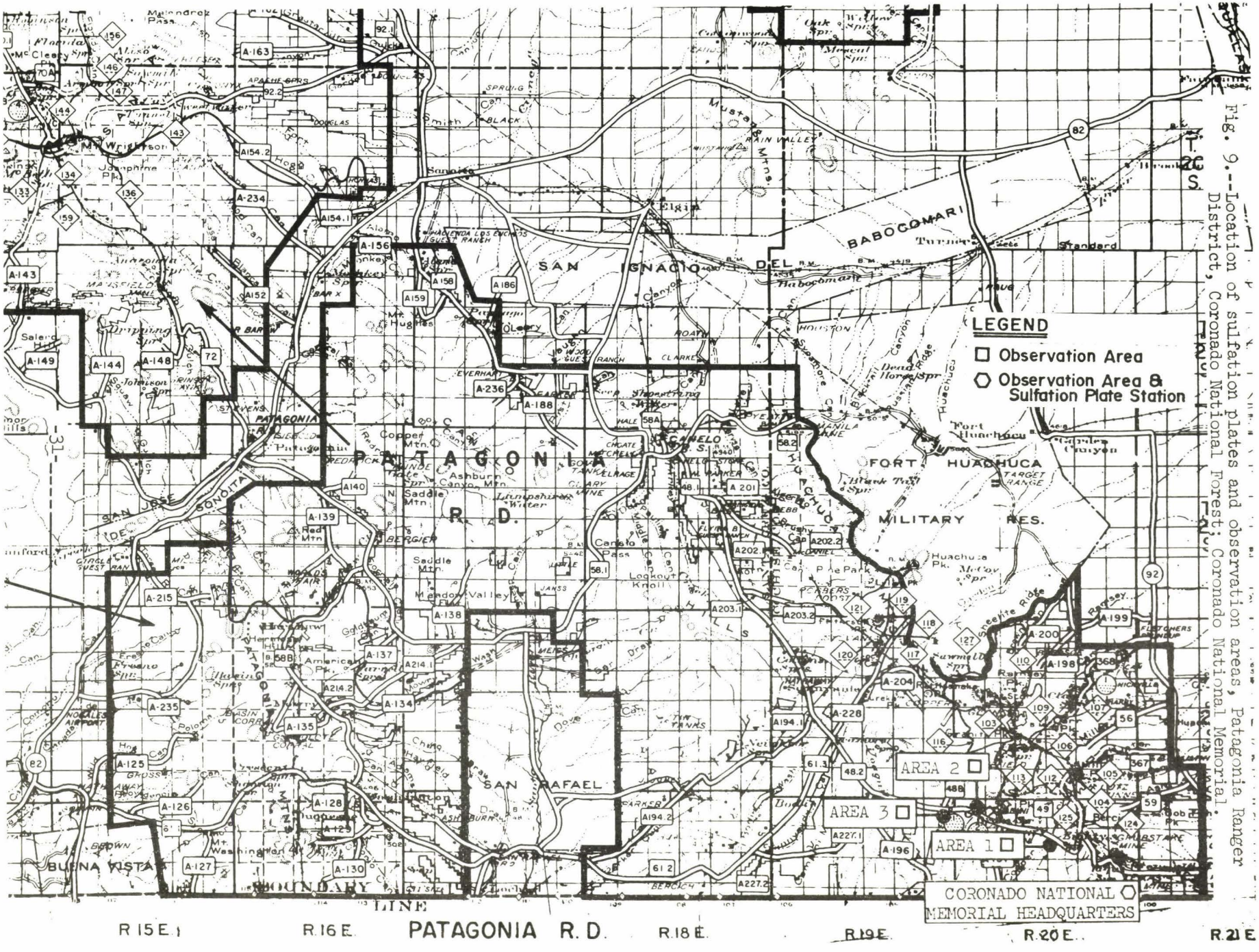
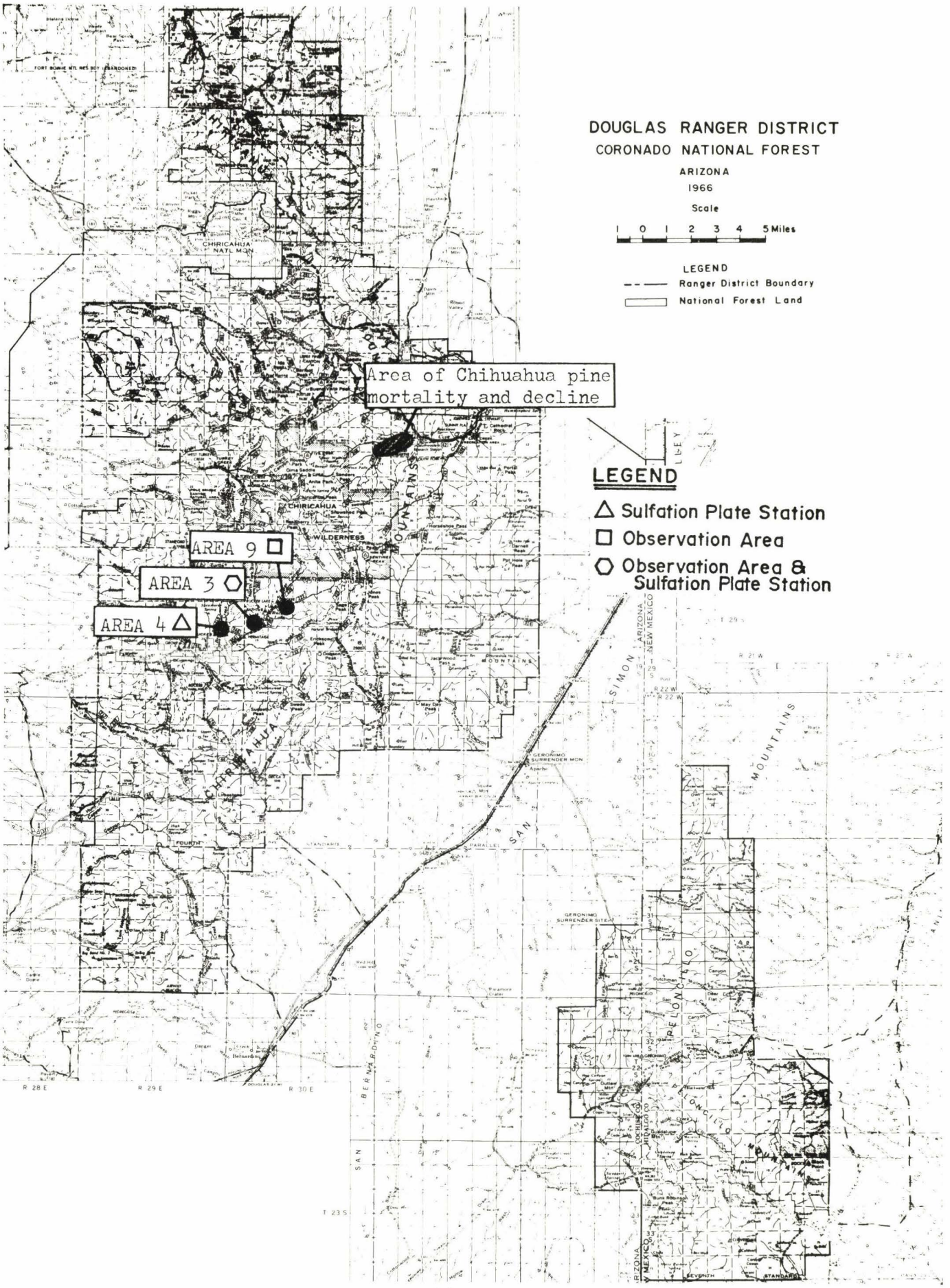


Fig. 9.--Location of sulfation plates and observation areas, Patagonia Ranger District, Coronado National Forest, Coronado National Memorial.

Fig. 10.--Location of sulfation plates and observation areas, Douglas Ranger District, Coronado National Forest.



Group III.--Lake Mohave Ranger District, Lake Mead National Recreation Area

Vegetation on selected areas of the Lake Mohave Ranger District (Fig. 11) was examined for symptoms of acute SO_2 injury in August 1971 and October 1972. During each visit, leaf necrosis was noted primarily on mulberry, ash, elm, and cottonwood (Fig. 12, 13). Dr. Fritz Went (3) attributes these symptoms on cottonwood and mulberry to high salt accumulation from irrigation water. High summer temperatures (115° F.) and drought stress are probably contributing factors. Marginal leaf necrosis, a typical symptom of drought injury, was noted during the 1971 survey on scrub oak growing in Christmas Tree Pass (12). Finally, a leaf browning or mottle was noted on willow (Fig. 14) approximately $1\frac{1}{2}$ miles up the lake from Katherine Landing.

The following plant species were examined for symptoms of acute SO_2 injury:

Ash (Fraxinus velutina)
Cottonwood (Populus spp.)
Creosote bush (Larrea tridentata)
Elm (Ulmus spp.)
Eucalyptus (Eucalyptus spp.)
Juniper (Juniperus spp.)
Mulberry (Morus alba)
Oak (Quercus spp.)
Paloverde (Cercidium spp.)
Pinyon (Pinus edulis)
Tamarisk (Tamarix gallica)
Willow (Salix spp.)
Yucca (Yucca spp.)

Discussion

As noted before, no symptoms of SO_2 injury were found. This could be expected for two reasons. First, the Mohave Generating Station has not yet operated at full capacity, and, second, because many plants growing in this arid climate (<4 inches precipitation per year) are resistant to SO_2 injury.

Data collected by the Desert Research Institute (3) indicate that (a) no injury to vegetation has been caused by emissions from the Mohave Generating Station, and (b) that SO_2 levels during 1971 were generally not higher than normal background levels expected for that area. There were, however, several instances of measurable SO_2 levels--the highest being 5 p.p.m. for a duration of 2-5 minutes at Bullhead City. Results of the 1972 biological study by the Desert Research Institute also indicate that no plant injury was caused by the Mohave Generating Station (Fritz Went, Personal Communication).

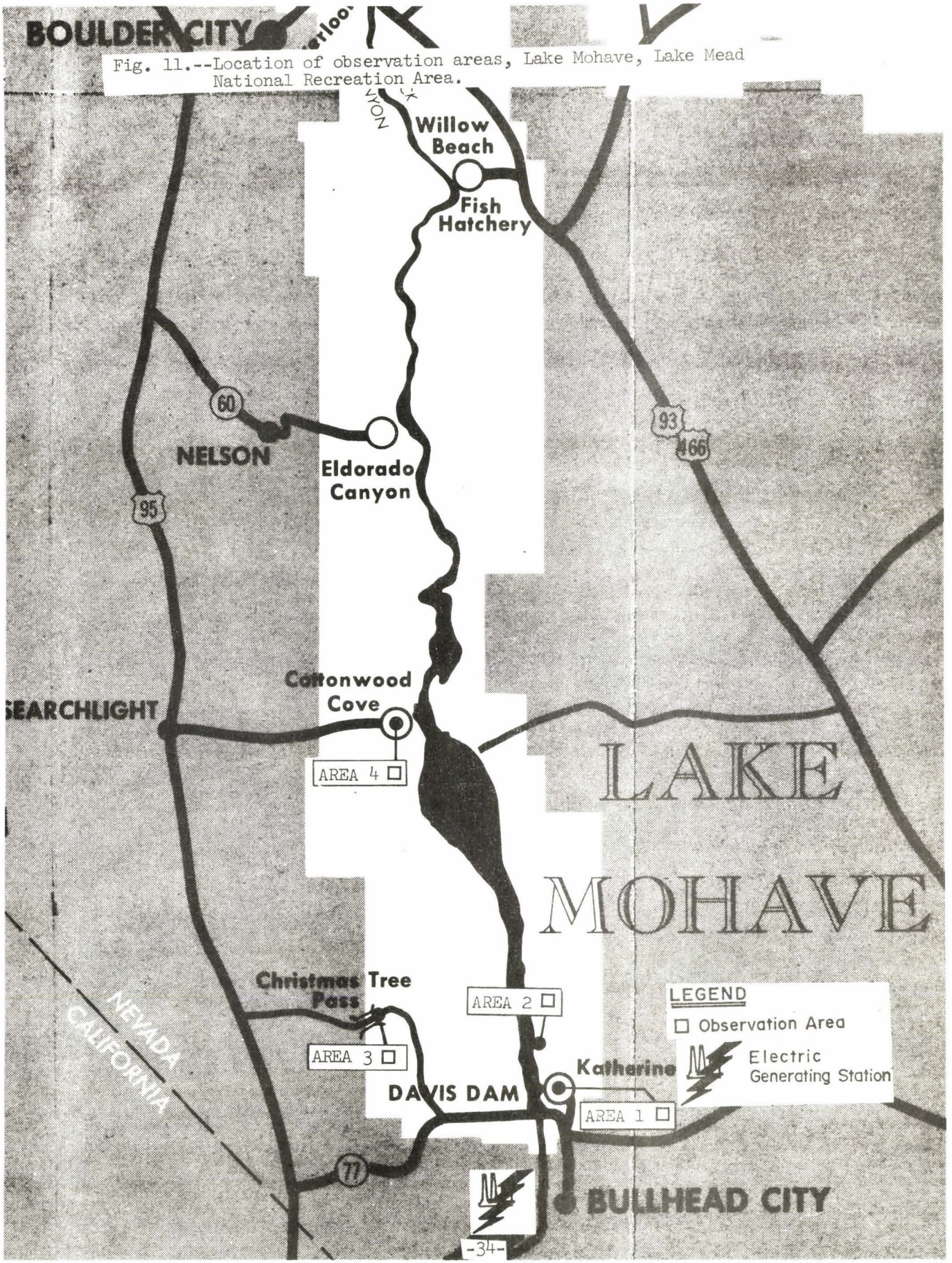


Fig. 11.--Location of observation areas, Lake Mohave, Lake Mead National Recreation Area.

Fig. 12 & 13. – Marginal necrosis on elm and cottonwood, probably salt and/or heat injury, Lake Mohave, Oct. 1972.

Fig. 14. – Leaf mottle of undetermined cause, on willow, Lake Mohave, Oct. 1972.

Group IV.--Glen Canyon National Recreation Area; Navajo Mountain, Navajo Indian Reservation; North and South Rim, Grand Canyon National Park; Jacob Lake Ranger District, Kaibab National Forest

Glen Canyon National Recreation Area

The survey for Glen Canyon National Recreation Area has been a cooperative effort between Forest Service Regions 3 and 4. This report will discuss the survey conducted on that portion of the Recreation Area in Arizona.

The observation areas at Wahweap Campground and Picnic Area and Lees Ferry are located approximately 6 and 11 miles, respectively, from the Navajo Generating Station (Fig. 15). Trees on these areas were examined in August 1971 and in July 1972 for foliage symptoms which might later be confused with symptoms of air pollution injury. Each year, marginal necrosis was noted on skunkbush and elm (Fig. 16, 17). Ash showed symptoms of both chlorosis and marginal necrosis (Fig. 18). Overall, marginal necrosis on all species appeared less severe in 1972. Sycamore exhibited this symptom in August 1971 (Fig. 19), but not in July 1972 (13). No foliage abnormalities, which might later be confused with air pollution injury, were noted either year in the observation areas at Lees Ferry.

Tree and shrub species which were examined include:

Arizona cypress (*Cupressus arizonica*)
Arizona sycamore (*Platanus wrightii*)
Ash (*Fraxinus velutina*)
Cottonwood (*Populus* spp.)
Elm (*Ulmus* spp.)
Honey locust (*Gleditsia triacanthos*)
Honeysuckle (*Lonicera* spp.)
Russian olive (*Elaeagnus angustifolia*)
Skunkbush (*Rhus trilobata*)
Tamarisk (*Tamarix gallica*)
White mulberry (*Morus alba*)
Willow (*Salix* spp.)

Thomas and Hendricks (21) suggest that chemical analysis of foliage for total and sulfate sulfur offers a possible method of diagnosis, particularly if leaves are analyzed before fumigation. As a first step in determining background levels and natural variability of sulfur in foliage of vegetation on the observation areas, samples of foliage from several tree species were analyzed for total sulfur content. The analysis results are presented in Table 10. These were composite samples taken from trees at Wahweap and Lees Ferry. Foliage was collected irrespective of age.

A second, more extensive, sampling of tree foliage was taken later, in July 1972, at Wahweap Picnic Area and Campground and at Lees Ferry. A total of 10 each Russian olive, elm, and poplar were individually sampled at Wahweap Picnic Area and Campground. A total of 10 willows were sampled at Lees Ferry. The results of the foliage analysis are presented in Table 11. This foliage was also collected irrespective of age. Sulfate sulfur, rather than total sulfur, was measured in this sample because information presented by Eaton (4) suggests that measuring sulfate sulfur, rather than total sulfur, is a better indication of sulfur deficiency or excess in plant tissue. Among other factors, available sulfur in the soil has an influence on levels of sulfur compounds in plant foliage. For this reason, soil samples were collected in several locations of Wahweap Campground and Picnic Area for analysis. Results of this soil analysis are presented in Table 12, and may be of use in future evaluations.

We realize that there are several inherent problems associated with foliage sampling, especially in areas like Wahweap Campground and Picnic Area, where different fertilizers of unknown composition have been applied. Analyzing foliage for sulfur content has not in itself proven to be a reliable method for determining if vegetation has been injured by SO_2, and it is still unclear as to whether the foliage should be analyzed for total sulfur, sulfate sulfur, or both. This background information may prove useful in the future task of evaluating any effects the generating station may have on nearby vegetation. In future sampling, care will be taken to standardize time of collection, age of foliage collected, and collection methods.

Sulfation plate data from the Wahweap Campground and Lees Ferry were collected by Region 4 personnel in cooperation with the National Park Service. Sulfation rates were extremely low.

Navajo Mountain, Navajo Indian Reservation

Navajo Mountain is located approximately 30 miles from the generating station (Fig. 15). The Mountain is the nearest site of ponderosa pine, spruce, and fir forest to the generating station. This area was examined in June and October 1971 for foliage symptoms which might later be confused with air pollution injury. None were found. Some observations about plant condition are noted in the 1971 survey report (14).

Trees and plants examined for foliage symptoms include the following:

Aspen (Populus tremuloides)
Douglas-fir (Pseudotsuga menziesii)
Engelmann spruce (Picea engelmannii)
Gambel oak (Quercus gambelii)
Juniper (Juniperus spp.)
Limber pine (Pinus flexilis)
Pinyon pine (Pinus edulis)
Ponderosa pine (Pinus ponderosa)
Snowberry (Symphoricarpos spp.)
White fir (Abies concolor)

Sulfation rates are presented in Table 13. These rates are very low. This station was terminated in May 1972.

Jacob Lake Ranger District, Kaibab National Forest

The location of the observation areas and sulfation plate stations are noted on Figure 20. These areas are from 40 to 50 miles from the Navajo Generating Station. They were examined in August 1971 and July 1972. No foliage symptoms were noted in either survey which might later be confused with air pollution injury. Some comments concerning tree and plant condition were presented in the 1971 survey report (15). The fading and browning of tree foliage was still noticeable along Route 89A, approximately 5 miles east of Jacob Lake (Fig. 20). In August 1971, the foliage of ponderosa pine, pinyon pine, Gambel oak, and other shrubs and forbs was affected. In July 1972, symptoms were noted only on coniferous foliage. The probable cause of this injury is drought. In addition, a needle mottle or fleck of undetermined cause (Fig. 6) was noted primarily on older ponderosa pine needles. This marking was noted only occasionally on current year's needles.

Tree and plant species examined included the following:

Aspen (Populus tremuloides)
Cliff rose (Cowania stansburiana)
Gambel oak (Quercus gambelii)
Juniper (Juniperus spp.)
Lupine (Lupinus spp.)
Pinyon pine (Pinus edulis)
Ponderosa pine (Pinus ponderosa)
Sagebrush (Artemisia spp.)
White fir (Abies concolor)

Sulfation plate data are presented in Table 14. Stations 1 and 2 were discontinued in November 1971; station 3 was discontinued in October 1972. With the exception of the January rate in area 2 and the May rate in area 3, the sulfation rates are extremely low. These two relatively high sulfation rates are probably a result of sulfation plate or analysis variation, rather than a variation in air quality.

North and South Rim, Grand Canyon National Park

The boundary of Grand Canyon National Park is located approximately 65 miles from the Navajo Generating Station. In August 1971, trees and plants were examined on the South Rim to make note of foliage symptoms which might later be confused with symptoms caused by air pollution. No symptoms resembling those caused by air pollution were found in any of the observation areas. Plant condition was discussed in the 1971 survey report (16). In July 1972, vegetation on both the North Rim and the South Rim was examined. The location of sulfation plate stations and observation areas is noted on Figure 21. Again, no foliage symptoms were found on the South Rim which might later be confused with air pollution injury. On the North Rim, several conifer diseases and an insect infestation were noted which were causing tree decline or foliage discoloration. These were as follows:

Needle cast of ponderosa pine which was probably caused by Davisomycella ponderosae

Southwestern dwarf mistletoe on ponderosa pine (Arceuthobium vaginatum subsp. cryptopodum)

Limb rust on ponderosa pine (Peridermium filamentosum)

White-fir dwarf mistletoe (Arceuthobium abietinum f. sp. concoloris)

Spruce broom rust (Chrysomyxa arctostaphyli)

White-fir needle miner (Epinotia meritana)

Tree and plant species examined during the 1971 and 1972 surveys include:

Aspen (Populus tremuloides)
Douglas-fir (Pseudotsuga menziesii)
Engelmann spruce (Picea engelmannii)
Gambel oak (Quercus gambelii)
Juniper (Juniperus spp.)

Pinyon pine (Pinus edulis)
Ponderosa pine (Pinus ponderosa)
White fir (Abies concolor)
Wild currant (Ribes spp.)
Wild rose (Rosa spp.)

Sulfation plate data for the period October 1970 to October 1971 are included in Table 15. These rates are comparable to rates recorded in other areas far from major sources of SO_2.

Discussion

There is little published information available concerning the effects of large, coal-burning electrical power generating stations on Southwestern vegetation. This lack of information is reflected in the Environmental Statement prepared for the Navajo Generating Station (24). Ecological baseline studies are presently underway (2), which should be helpful in assessing any effects to vegetation which may result from the power station operation.

Estimates by Dames and Moore,[4/] which are presented in the Environmental Statement, indicate that estimated maximum SO_2 and NO_x ground concentrations, using coal of average sulfur content (0.51), could be as high as 0.43 p.p.m. SO_2 and 0.56 p.p.m. NO_x. They further estimate that (a) stack emissions will be in the general vicinity of Navajo Mountain approximately 33% of the time, but that levels of SO_2 will be low; (b) stack emissions are expected to be in the direction of Lees Ferry and Marble Canyon approximately 13% of the time, but concentrations of SO_2 may be relatively high; (c) stack emissions are expected to be in the general direction of Wahweap Campground only 5.2% of the time, and SO_2 concentrations will be low; (d) calm wind conditions are expected 13.2% of the time.

An evaluation of air pollution concentrations from the Navajo Station and the proposed Kaiparowits Station was prepared by the Environmental Protection Agency (5), and is presented in appendix 1 of the Navajo Environmental Statement. In this report, the Environmental Protection Agency estimates that SO_2 and NO_x concentrations would be 0.2 p.p.m. 18 miles downwind of the Navajo Generating Station. It also indicates that the expected SO_2 levels from the station should be increased by 200% for the case when the limits of rejection for sulfur (1.5%) and the heating value of the Black Mesa coal are approached concurrently. Thus, there appears to be a possibility that SO_2 levels may be higher than expected; however, the potential for plant injury resulting from these SO_2 levels is unknown.

4/ Dames and Moore, Consulting Engineers in the Applied Earth Sciences, Atlanta, Georgia.

Based on survey experience in other areas, it seems unlikely that acute SO_2 injury will occur to forest vegetation on the Jacob Lake Ranger District, Grand Canyon National Park, and Navajo Mountain. The possibility for plant injury is greater for some areas of Glen Canyon National Recreation Area.

Table 10.--Foliage analysis[1/] for total sulfur, Glen Canyon National Recreation Area.

Location	Species	No. of trees	Sample identification	% Total sulfur (Dry Wt.)	
				1971	1972
Wahweap Picnic Area entrance	Elm	5	1	0.13	0.07
N. side Wahweap Picnic Area	Poplar	5	2	0.38	0.52
S. side Wahweap Picnic Area	Russian olive	16	3	0.36	0.37
Approx. $\frac{1}{4}$ mile upstream Lees Ferry store	Cotton-wood	3	4	--	1.15
Approx. $\frac{1}{4}$ mile upstream Lees Ferry store	Willow	4	5	--	0.22
Approx. 150 yards upstream of first pullout along River Drive at Lees Ferry	Willow	4	6	--	0.46

1/ Analyzed by Controls for Environmental Pollution, Inc., P. O. Box 5351, Santa Fe, New Mexico 87501.

Table 11.--Foliage analysis[1/] for sulfate sulfur, Glen Canyon National Recreation Area.

Location	Species	Sample identification	% Sulfate sulfur (Dry Wt.)
Approx. $\frac{1}{4}$ mile upstream Lees Ferry store	Willow	101	0.17
		102	0.16
		103	0.13
		104	0.17
		105	0.17
Near intersection of main road and service road downstream Lees Ferry store	Willow	106	0.66
		107	0.77
		108	0.48
		109	0.69
		110	0.37
Across from Wahweap Picnic Area entrance	Russian olive	111	0.21
		112	0.20
		113	0.24
		114	0.23
		115	0.29
		116	0.26
		117	0.20
		118	0.16
		119	0.30
		120	0.20
Wahweap Picnic Area	Elm	121	0.02
		122	0.02
		123	0.02
		124	0.03
		125	0.03
		126	0.02
		127	0.02
		128	0.02
		129	0.01
		130	0.01
South side of Wahweap Campground	Poplar	131	0.30
		132	0.21
		133	0.20
		134	0.22
		135	0.28
		136	0.31
		137	0.32
		138	0.32
		139	0.14
		140	0.16

1/ Analyzed by Controls for Environmental Pollution, Inc., P. O. Box 5351, Santa Fe, New Mexico 87501

Table 12.--Soil analysis[1] results, Glen Canyon National Recreation Area.

	Sample Number[2]		Sample Number[2]		Sample Number[2]		
	113	116	117	122	131	133	135
Soil pH	8.1	8.2	8.5	8.1	8.2	8.2	8.5
Buffer pH							
Excess Lime	M	M	L	VH	L	M	L
% Soluble Salts	.11	.04	.03	.11	.04	.06	.04
Analysis of nutrient elements is in Parts per Million (ppm). For approximate pounds per acre six inches multiply ppm by two.							
% Organic Matter							
Residual Nitrate N							
Available Phosphorus	9-L	9-L	6-VL	7-L	18-M	12-L	5-VL
Exchangeable Potassium	300-H	210-M	140-L	180-M	270-M	240-M	110-L
Exchangeable Magnesium	150-L	110-L	140-L	110-L	130-L	120-L	100-L
Exchangeable Calcium	2400-M	2600-H	2300-M	2600-H	2100-M	2500-M	2500-M
Exchangeable Sodium	110-M	40-M	60-M	110-M	60-M	50-M	70-M
Available Sulfate Sulfur	89-H	24-L	23-L	121-VH	12-L	67-H	56-H

RELATION OF CEC TO SOIL TEXTURE

0-10 Sand
10-15 Loamy Sand
15-20 Sandy Loam
20-27 Loam
28-50 Clay Loam
50+ Clay

CODES

REPORT OF ANALYSIS

L=Low
M=Medium
H=High
V=Very

Me =Milliequivalents
gm =Grams
CEC=Cation Exchange Capacity

Sample Number[2]	ACTUAL AND SUGGESTED % OF CEC										CEC
	Actual H%	Suggest H%	Actual K%	Suggest K%	Actual Mg%	Suggest Mg%	Actual Ca%	Suggest Ca%	Actual Na%	Suggest Na%	
113	.0	0-5	5.5	4.1 -7	8.2	15-20	82.7	65-75	3.4	0-2	14.5
116	.0	0-5	3.4	4.1 -7	6.1	15-20	89.0	65-75	1.3	0-2	14.6
117	.0	0-5	2.9	4.6 -7	8.9	15-20	85.8	65-75	2.2	0-2	13.4
122	.0	0-5	3.3	4.0 -7	6.0	15-20	87.2	65-75	3.3	0-2	14.9
131	.0	0-5	5.5	4.9 -7	8.7	15-20	83.3	65-75	2.3	0-2	12.6
133	.0	0-5	4.1	4.2 -7	6.9	15-20	87.4	65-75	1.3	0-2	14.3
135	.0	0-5	2.1	4.4 -7	5.7	15-20	89.9	65-75	2.1	0-2	13.9

1/ Analyzed by Harris Laboratories, Inc., P. O. Box 80837, Lincoln, Nebraska 68501.
2/ Soil sample number corresponds to tree number where sample was obtained.

Table 13.--Sulfation plate data, Navajo Mountain, Navajo Indian Reservation.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	33	** <Detectable minimum
Aug.	30	<Detectable minimum
Sep.-Oct.	62	<Detectable minimum
Nov.	29	<Detectable minimum
Dec.	33	<Detectable minimum
Jan. 1972	28	<Detectable minimum
Feb.	28	<Detectable minimum
Mar.	36	<Detectable minimum
Apr.	28	3.5

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Jul. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-Apr. 1972 - 1.3

Table 14.--Sulfation plate data, Jacob Lake Ranger District, Kaibab National Forest.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Area 1		
Nov. 1970	29	** <Detectable minimum
Dec.	49	1.9
Jan. 1971	13	<Detectable minimum
Feb.	30	<Detectable minimum
Mar.	29	1.8
Apr.	28	3.7
May	34	<Detectable minimum
Jun.	29	<Detectable minimum
Jul.	33	2.6
Aug.	29	<Detectable minimum
Sep.	29	<Detectable minimum
Oct.	28	<Detectable minimum
Area 2		
Nov. 1970	29	<Detectable minimum
Dec.	48	2.4
Jan. 1971	14	8.3
Feb.	29	<Detectable minimum
Mar.	30	<Detectable minimum
Apr.	28	1.9
May	34	<Detectable minimum
Jun.	29	<Detectable minimum
Jul.	33	2.6
Aug.	31	1.5
Sep.	27	<Detectable minimum
Oct.	28	<Detectable minimum

Table 14.--Sulfation plate data, Jacob Lake Ranger District, Kaibab National Forest (cont'd.).

Area 3

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jun. 1971	29	4.0
Jul.	32	** <Detectable minimum
Aug.	31	1.5
Sep.	27	<Detectable minimum
Oct.	28	<Detectable minimum
Nov.	33	<Detectable minimum
Dec.	30	<Detectable minimum
Jan. 1972	33	<Detectable minimum
Feb.	31	<Detectable minimum
Mar.	28	<Detectable minimum
Apr.	44	<Detectable minimum
May	21	8.3
Jun.	24	<Detectable minimum
Jul.	32	<Detectable minimum
Aug.	32	<Detectable minimum
Sep.	27	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Nov. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972-Sep. 1972 - 1.3

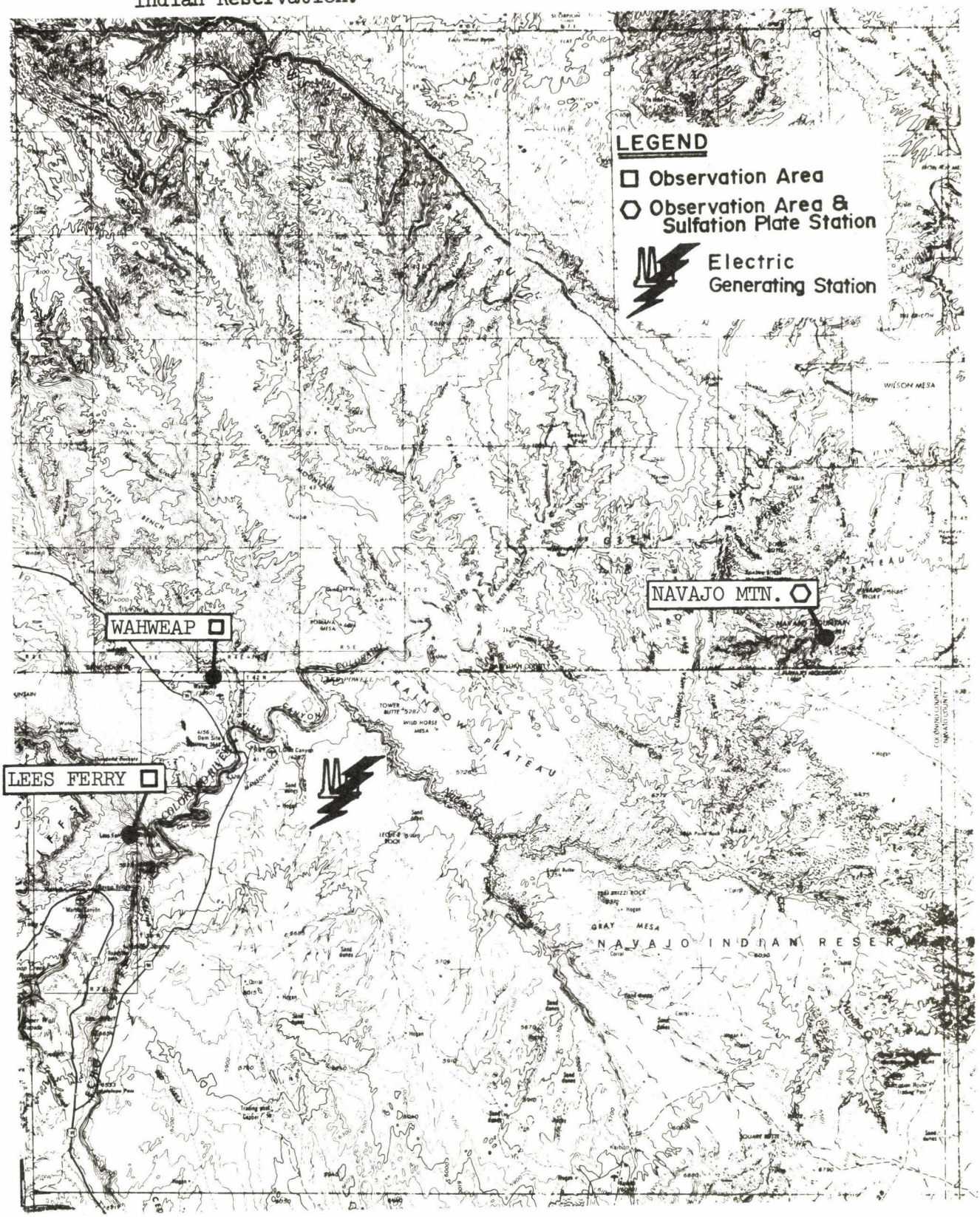
Table 15.--Sulfation plate data, Grand Canyon National Park.

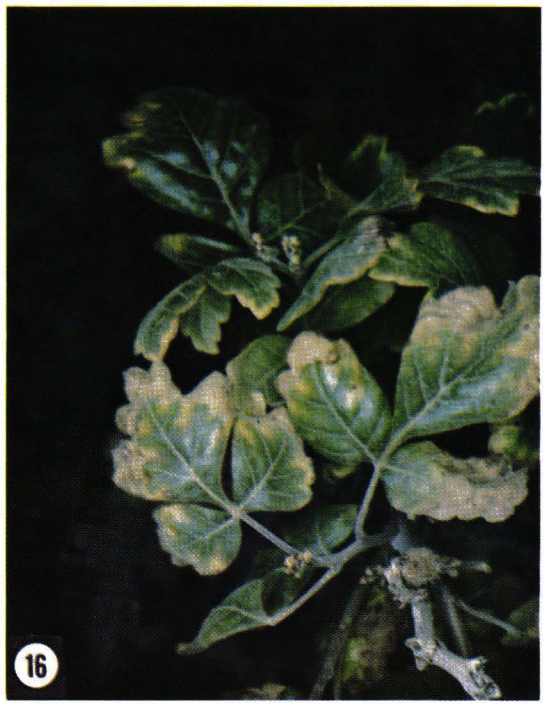
Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Area 1		
Oct. 1970	26	3.3
Nov.	29	** <Detectable minimum
Dec.	34	<Detectable minimum
Jan. 1971	25	<Detectable minimum
Feb.	--	--
Mar.	31	3.4
Apr.	30	1.7
May	39	<Detectable minimum
Jun.	22	1.8
Jul.	31	<Detectable minimum
Aug.	30	2.9
Sep.	29	<Detectable minimum
Oct.	31	<Detectable minimum
Area 2		
Oct. 1970	26	<Detectable minimum
Nov.	29	<Detectable minimum
Dec.	30	<Detectable minimum
Jan. 1971	29	2.0
Feb.	25	<Detectable minimum
Mar.	34	2.5
Apr.	27	1.9
May	30	<Detectable minimum
Jun.	18	<Detectable minimum
Jul.	28	<Detectable minimum
Aug.	30	3.7
Sep.	22	<Detectable minimum
Oct.	37	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Oct. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971 - 1.3

Fig. 15.--Location of sulfation plate and observation areas, Glen Canyon National Recreation Area; Navajo Mountain, Navajo Indian Reservation.





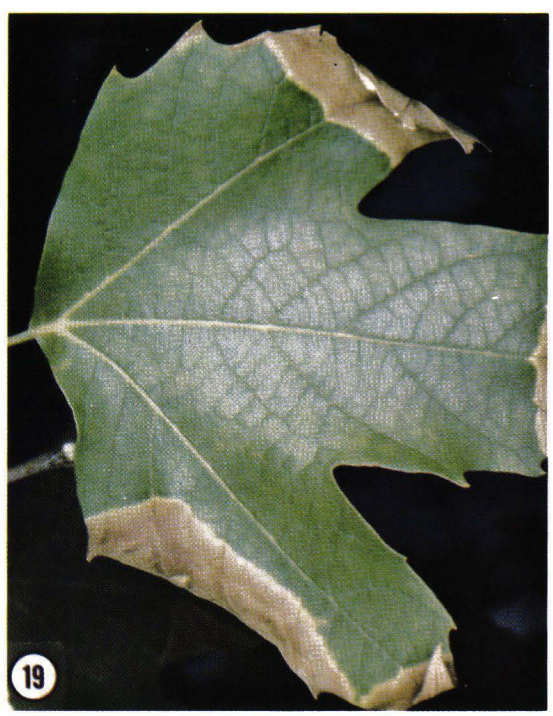
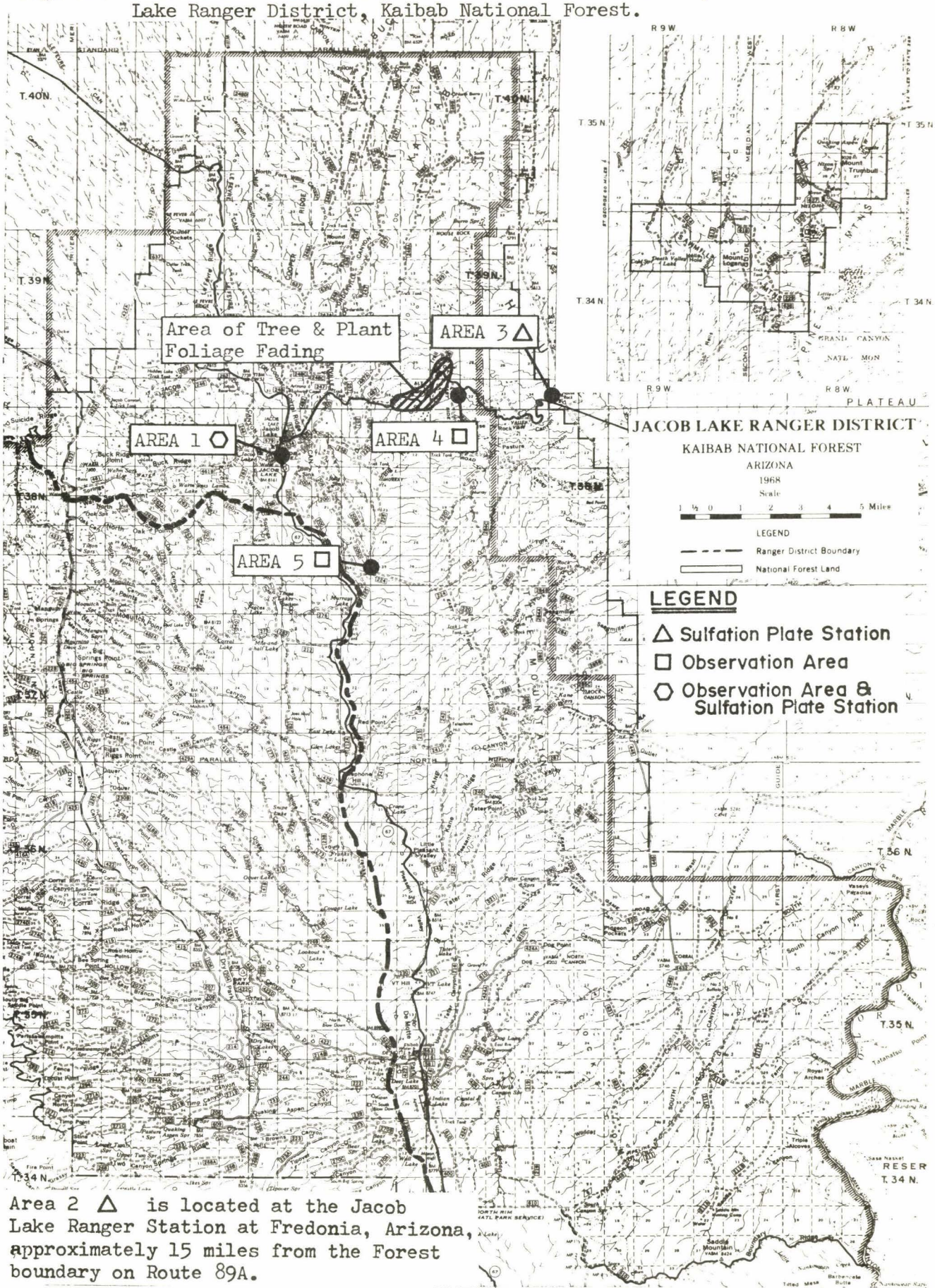


Fig. 16 & 17. – Marginal necrosis on skunkbush and elm, probably drought or heat injury, Glen Canyon National Recreation Area, Jul. 1972.

Fig. 18. – Chlorosis and marginal necrosis of ash, probably heat injury and iron deficiency, Glen Canyon National Recreation Area, Jul. 1972.

Fig. 19. – Marginal necrosis on sycamore, probably drought or heat injury, Glen Canyon National Recreation Area, Aug. 1971.

Fig. 20.--Location of sulfation plates and observation areas, Jacob Lake Ranger District, Kaibab National Forest.



Area 2 △ is located at the Jacob Lake Ranger Station at Fredonia, Arizona, approximately 15 miles from the Forest boundary on Route 89A.

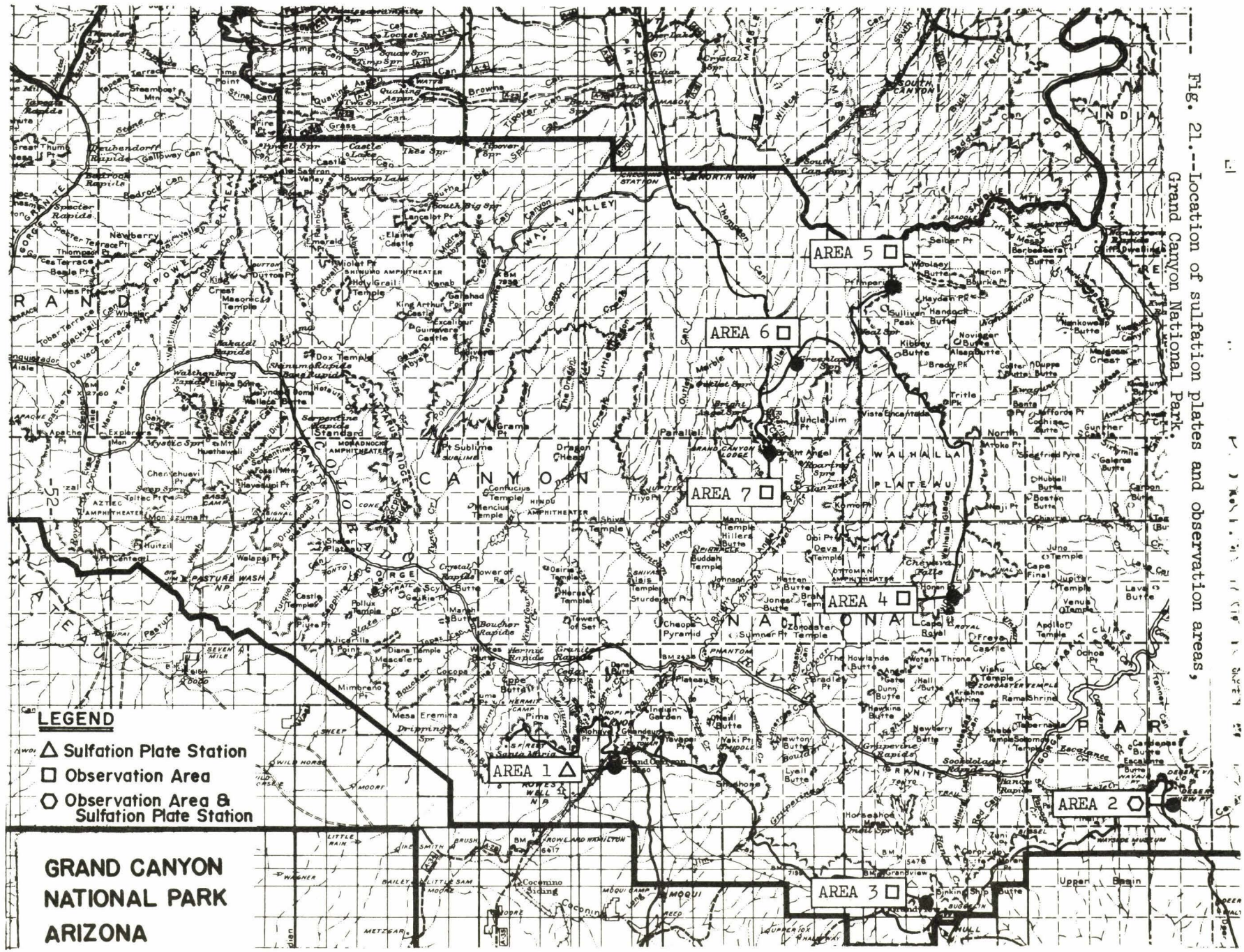


Fig. 21.--Location of sulfation plates and observation areas, Grand Canyon National Park.

Group V.--Silver City Ranger District, Gila National Forest; Mimbres Ranger District, Gila National Forest; Wilderness Ranger District, Gila National Forest; Glenwood Ranger District, Gila National Forest

Silver City Ranger District, Gila National Forest

The observation areas and sulfation plate stations on the Silver City Ranger District are from 10 to 16 miles from the copper smelter at Hurley, New Mexico. The observation area at Ft. Bayard Hospital is approximately 7 miles from the smelter (Fig. 22). These observation areas were examined in September 1971 and in July and August 1972.

During the 1971 survey, no symptoms of acute SO_2 injury were found in any of the areas which were examined. The following leaf and needle markings were noted in the 1971 survey report (17):

1. Drought-caused marginal leaf necrosis on Wright silk tassel (Fig. 23) in area 1.

2. Needle mottle or fleck on both current and older ponderosa pine needles (area 1 and area 7) (Fig. 6).

3. Chlorotic cottonwood foliage at Ft. Bayard Hospital (area 9).

4. Chlorotic foliage of willow and Arizona alder (area 7).

During the 1972 survey, no foliage symptoms were found in any observation area which were identified as being caused by SO_2 fumigations. Roadside vegetation was examined 1 to 2 miles north of Hurley on Highway 180, and symptoms typical of acute SO_2 injury were noted on an estimated 5% or less of the sunflower, bindweed, and velvetweed (Fig. 24) plants examined. Velvetweed appeared to be the most sensitive plant species in that area.

On the Ft. Bayard Hospital grounds (area 9), symptoms resembling those caused by SO_2 were noted on Lombardy poplar (Fig. 25). In addition, necrotic areas were noticed on elm foliage in the same area (Fig. 26, 27). For the Lombardy poplar, 80% of the trees examined had these foliage symptoms; an estimated 75% of the leaves on each tree had markings. For the elms, 10% of the trees examined had foliage symptoms. Of the trees which had symptoms, an estimated 40% of the leaves on each tree had markings. The cause(s) of these foliage abnormalities have not been determined, and will have to be evaluated further. We are reluctant to implicate SO_2 because several plant species, which have proven to be relatively sensitive to SO_2 in other areas, had no symptoms of SO_2 injury. These species include globe mallow, velvetweed, sunflower, bindweed, brickelbush, and skunkbush.

In the 1971 report, some mention was made of the chlorotic willow and alder foliage in area 7. In the summer of 1970, Dr. Walter W. Heck[5/] noted that these willows showed the classic chlorotic mottle pattern which has been associated with SO_2 in the East (Fig. 28) (W. W. Heck, unpublished Southwest trip report). We have examined this area for 2 years, and now believe that it is probably an iron deficiency problem, rather than a result of SO_2 fumigation. The primary reason for reaching this conclusion is that several plant species, which have proven to be relatively sensitive to SO_2 in other areas, had no symptoms of SO_2 injury. These species include brickelbush, globe mallow, bindweed, bee plant, and velvetweed.

Foliage symptoms of unknown cause on box elder and sumac (Fig. 29,30) were noted within 1 mile of area 7. Similar symptoms have been noted in several areas far from sources of air pollution. Therefore, it is unlikely that the symptoms near area 7 are associated with SO_2 injury.

Tree and plant species examined for symptoms of SO_2 injury include:

Alligator juniper (*Juniperus deppeana*)
Arizona alder (*Alnus oblongifolia*)
Arizona walnut (*Juglans major*)
Bee plant (*Cleome serrulata*)
Bindweed (*Convolvulus* spp.)
Box elder (*Acer negundo*)
Brickelbush (*Brickellia* spp.)
Chihuahua pine (*Pinus leiophylla* var. *chihuahuana*)
Cockelbur (*Xanthium strumarium*)
Cottonwood (*Populus* spp.)
Elm (*Ulmus* spp.)
Fendlerbush (*Fendlera rupicola*)
Gambel oak (*Quercus gambelii*)
Globe mallow (*Sphaeralcea* spp.)
Gray oak (*Quercus grisea*)
Lamb's-quarter (*Chenopodium album*)
Lombardy poplar (*Populus nigra* var. *italica*)
Lupine (*Lupinus* spp.)
Mountain mahogany (*Cercocarpus* spp.)
New Mexican locust (*Robinia neomexicana*)
Nightshade (*Solanum* spp.)
One-seed juniper (*Juniperus monosperma*)
Pinyon pine (*Pinus edulis*)
Poison ivy (*Toxicodendron radicans*)
Ponderosa pine (*Pinus ponderosa*)
Pricklepoppy (*Argemone* spp.)
Sacred datura (*Datura meteloides*)
Skunkbush (*Rhus trilobata*)

5/ Dr. Walter W. Heck, Plant Physiologist, Southern Region, ARS, USDA, North Carolina State University, Raleigh, North Carolina.

Southwestern white pine (Pinus strobiformis)
Sumac (Rhus spp.)
Sunflower (Helianthus spp.)
Velvetweed (Gaura parviflora)
White sweetclover (Melilotus albus)
Wild cherry (Prunus spp.)
Wild geranium (Geranium caespitosum)
Wild grape (Vitis spp.)
Willow (Salix spp.)
Wright silk tassel (Garrya wrightii)

Sulfation plate data for the period October 1970 to October 1972 are presented in Table 16. These rates are quite low for most months; however, the sulfation rates recorded for some months are comparable to the rates recorded in areas where plant injury has been found. The sulfation plate station in area 2 was discontinued in November 1972.

Mimbres Ranger District, Gila National Forest; Wilderness Ranger District, Gila National Forest; Glenwood Ranger District, Gila National Forest

The observation areas on the Mimbres Ranger District are located approximately 15 miles from the smelter at Hurley, New Mexico. The observation areas on the Wilderness and Glenwood Ranger Districts are approximately 30 and 50 miles, respectively, from this same smelter. These areas were examined in July and August 1972 for symptoms of acute SO_2 injury. No symptoms of injury were found on any area. The location of the observation areas and sulfation plate stations are note on Figures 31 and 32.

Tree and plant species which were examined include:

Arizona alder (Alnus oblongifolia)
Arizona walnut (Juglans major)
Box elder (Acer negundo)
Brickelbush (Brickellia spp.)
Cockelbur (Xanthium strumarium)
Cottonwood (Populus spp.)
Gambel oak (Quercus gambelii)
Globe mallow (Sphaeralcea spp.)
Grape (Vitis spp.)
Lupine (Lupinus spp.)
Ponderosa pine (Pinus ponderosa)
Sunflower (Helianthus spp.)
Velvetweed (Gaura parviflora)
Willow (Salix spp.)

Dead and declining Arizona alder trees were examined in the Catwalk Recreation Area, Glenwood Ranger District (area 1). Deposition of sand and gravel around the trees by a series of floods from 1967 to 1971 has probably contributed to this condition.

Sulfation plate data for the period October 1970 to October 1972 are presented in Table 17. These sulfation rates are comparable to the rates recorded in areas far from known sources of SO_2.

Discussion

During the course of our Region-wide air pollution surveys, symptoms of acute SO_2 injury have not been observed more than 7 miles from the source. Sulfation rates recorded for the Wilderness, Mimbres, and Glenwood Ranger Districts have been low. The sulfation rates recorded on the Silver City Ranger District have been mostly low. However, rates were recorded for some months which were comparable to rates recorded in other areas of the Region where injury was found. Therefore, based on previous survey experience, and on our sulfation plate data, we do not expect to find symptoms of acute SO_2 injury on the Wilderness, Glenwood, or Mimbres Ranger Districts. The potential for possible injury is higher for some areas of the Silver City Ranger District and the Ft. Bayard Hospital area. Continued examination of these areas is necessary in order to determine if SO_2 injury is occurring.

Table 16.--Sulfation plate data, Silver City Ranger District, Gila National Forest.

Area 1 (Plate 1)

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Oct. 1970	33	3.2
Nov.	27	3.2
Dec.	35	3.6
Jan. 1971	24	7.3
Feb.	31	2.2
Mar.	31	5.8
Apr.	32	5.0
May	25	** <Detectable minimum
Jun.	40	3.6
Jul.	--	--
Aug.	33	1.4
Sep.	31	<Detectable minimum
Oct.	27	<Detectable minimum
Nov.	41	4.4
Dec.	35	6.6
Jan. 1972	34	3.9
Feb.	27	4.9
Mar.	28	<Detectable minimum
Apr.	29	<Detectable minimum
May	29	6.0
Jun.	28	<Detectable minimum
Jul.	23	<Detectable minimum
Aug.	41	3.0
Sep.	27	5.3
Oct.	30	1.9
Nov.	28	<Detectable minimum
Dec.	38	4.3
Jan. 1973	25	2.8

Area 1 (Plate 1A)

Jun. 1971	40	3.9
Jul.	--	--
Aug.	33	1.4
Sep.	31	1.3
Oct.	27	1.5
Nov.	41	3.5
Dec.	35	6.9

Table 16.--Sulfation plate data, Silver City Ranger District, Gila National Forest (cont'd.)

Area 1 (Plate 1A)

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jan. 1972	34	3.4
Feb.	27	4.3
Mar.	28	** <Detectable minimum
Apr.	29	<Detectable minimum
May	29	<Detectable minimum
Jun.	28	<Detectable minimum
Jul.	23	<Detectable minimum
Aug.	41	2.3
Sep.	27	4.5
Oct.	30	<Detectable minimum
Nov.	28	2.5
Dec.	38	3.8
Jan. 1973	25	<Detectable minimum

Area 2

Oct. 1970	34	4.4
Nov.	26	5.4
Dec.	35	1.7
Jan. 1971	24	2.4
Feb.	31	2.1
Mar.	31	2.8
Apr.	32	4.0
May	31	<Detectable minimum
Jun.	34	<Detectable minimum
Jul.	--	--
Aug.	30	4.4
Sep.	31	2.6
Oct.	27	1.5
Nov.	45	3.7
Dec.	38	4.4
Jan. 1972	29	<Detectable minimum
Feb.	26	<Detectable minimum
Mar.	28	2.7
Apr.	30	<Detectable minimum
May	28	<Detectable minimum
Jun.	28	<Detectable minimum
Jul.	22	<Detectable minimum
Aug.	42	3.2
Sep.	26	5.6
Oct.	33	3.0

Table 16.--Sulfation plate data, Silver City Ranger District, Gila National Forest (cont'd.).

Area 3

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Oct. 1970	27	** <Detectable minimum
Nov.	27	<Detectable minimum
Dec.	43	3.8
Jan. 1971	16	<Detectable minimum
Feb.	32	3.4
Mar.	30	6.0
Apr.	31	4.5
May	32	1.8
Jun.	34	6.5
Jul.	--	--
Aug.	33	<Detectable minimum
Sep.	31	1.3
Oct.	27	<Detectable minimum
Nov.	41	<Detectable minimum
Dec.	35	1.6
Jan. 1972	34	<Detectable minimum
Feb.	27	3.6
Mar.	28	<Detectable minimum
Apr.	29	<Detectable minimum
May	29	<Detectable minimum
Jun.	28	<Detectable minimum
Jul.	23	<Detectable minimum
Aug.	41	2.0
Sep.	27	<Detectable minimum
Oct.	30	3.3
Nov.	28	<Detectable minimum
Dec.	33	<Detectable minimum
Jan. 1973	30	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Oct. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972-Jan. 1973 - 1.3

Table 17.--Sulfation plate data; Mimbres Ranger District, Gila National Forest; Wilderness Ranger District, Gila National Forest; Glenwood Ranger District, Gila National Forest.

Area 4 - Mimbres Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Nov. 1970	16	** <Detectable minimum
Dec.	30	1.5
Jan. 1971	31	1.9
Feb.	28	2.1
Mar.	31	4.1
Apr.	--	--
May	31	<Detectable minimum
Jun.	30	<Detectable minimum
Jul.	31	<Detectable minimum
Aug.	31	<Detectable minimum
Sep.	30	<Detectable minimum
Oct.	30	<Detectable minimum
Nov.	30	<Detectable minimum
Dec.	31	<Detectable minimum
Jan. 1972	31	<Detectable minimum
Feb.	29	<Detectable minimum
Mar.	31	<Detectable minimum
Apr.	29	<Detectable minimum
May	30	<Detectable minimum
Jun.	31	<Detectable minimum
Jul.	31	2.0
Aug.	30	<Detectable minimum
Sep.	32	1.8
Oct.	25	<Detectable minimum

Area 5 - Wilderness Ranger District

Oct. 1970	16	4.0
Nov.	26	2.9
Dec.	30	1.9
Jan. 1971	--	--
Feb.	23	<Detectable minimum
Mar.	35	3.6
Apr.	33	3.2
May	28	1.4
Jun.	37	1.1
Jul.	23	2.0
Aug.	45	<Detectable minimum
Sep.	16	<Detectable minimum

Table 17.--Sulfation plate data; Mimbres Ranger District, Gila National Forest; Wilderness Ranger District, Gila National Forest; Glenwood Ranger District, Gila National Forest (cont'd.).

Area 5 - Wilderness Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Oct.-Nov. 1971	54	** <Detectable minimum
Nov.-Dec.	15	<Detectable minimum
Dec.	27	<Detectable minimum
Jan. 1972	27	<Detectable minimum
Feb.	31	<Detectable minimum
Mar.-Apr.	40	2.5
Apr.	21	<Detectable minimum
May	33	<Detectable minimum
Jun.	27	<Detectable minimum
Jul.	30	<Detectable minimum
Aug.	38	1.7
Sep.	34	<Detectable minimum

Area 6 - Glenwood Ranger District

May 1971	32	1.3
Jun.	30	1.2
Jul.	31	<Detectable minimum
Aug.	31	<Detectable minimum
Sep.	30	<Detectable minimum
Oct.	31	<Detectable minimum
Nov.	30	<Detectable minimum
Dec.	33	<Detectable minimum
Jan. 1972	29	2.8
Feb.	35	<Detectable minimum
Mar.	27	<Detectable minimum
Apr.	26	<Detectable minimum
May	33	<Detectable minimum
Jun.	32	<Detectable minimum
Jul.	31	<Detectable minimum
Aug.	34	1.9
Sep.	27	3.6
Oct.	29	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Oct. 1970-Feb. 1971 - 1.2
Mar. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972-Oct. 1972 - 1.3

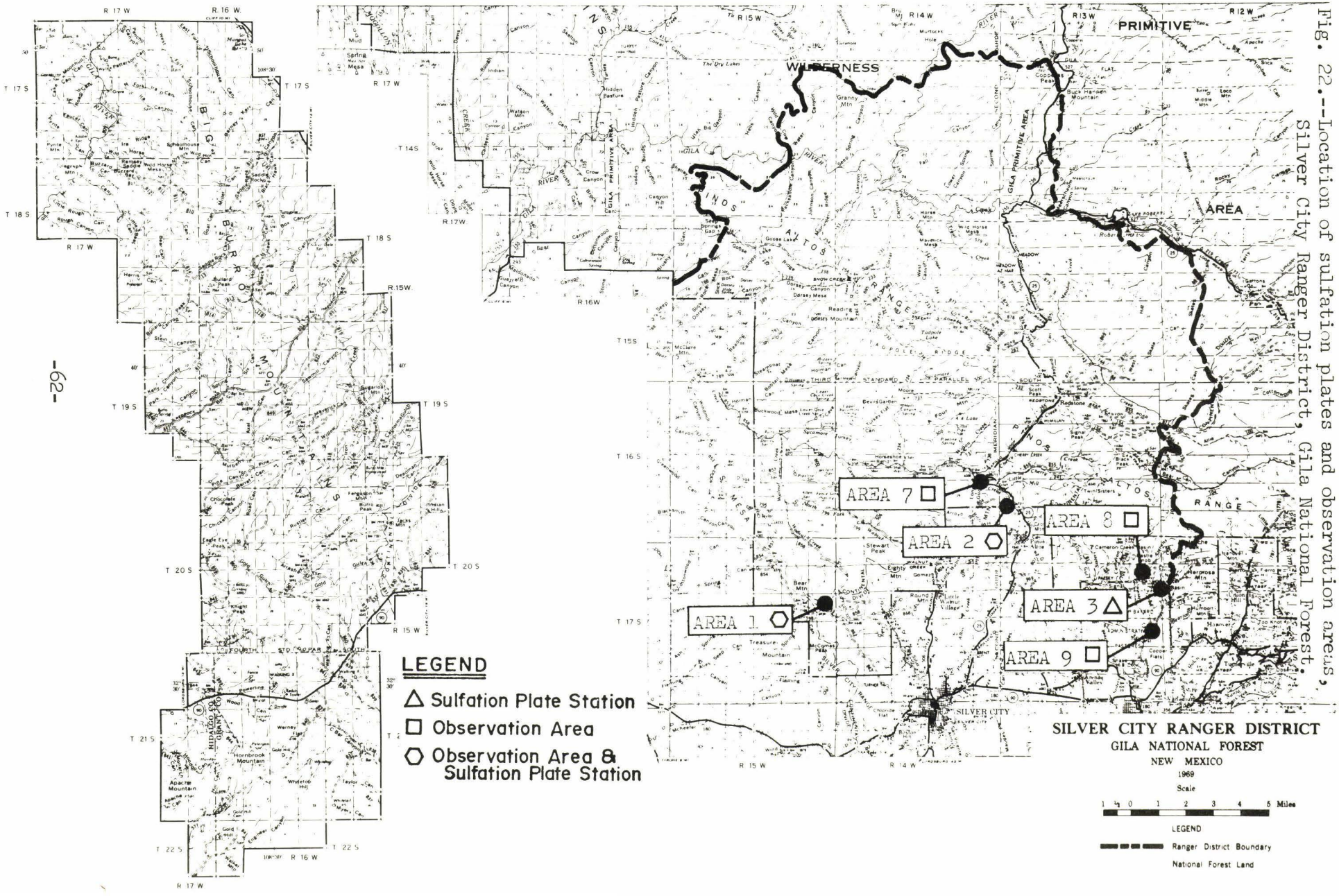


Fig. 22.--Location of sulfation plates and observation areas, Silver City Ranger District, Gila National Forest.

Fig. 23. – Drought-caused marginal leaf necrosis on Wright silk tassel, Silver City Ranger District, Sep. 1971.

Fig. 24. – SO_2 injury to velvetweed, Hurley, New Mexico, Aug. 1972.

Fig. 25. – Symptoms resembling SO_2 injury to Lombardy poplar, Ft. Bayard, New Mexico, Aug. 1972.

Fig. 26. – Upper surfaces of elm foliage with necrotic areas of unknown cause, Ft. Bayard, New Mexico, Aug. 1972.

Fig. 27. – Lower surfaces of elm foliage with necrotic areas of unknown cause, Ft. Bayard, New Mexico, Aug. 1972.

Fig. 28. – Chlorotic foliage of willow, probably caused by iron deficiency, Silver City Ranger District, Aug. 1972.

Fig. 29 & 30. – Box elder and sumac foliage abnormalities of causes other than SO_2 Silver City Ranger District, Aug. 1972.

Fig. 31.--Location of sulfation plate stations and observation areas, Mimbres Ranger District and Wilderness Ranger District, Gila National Forest.

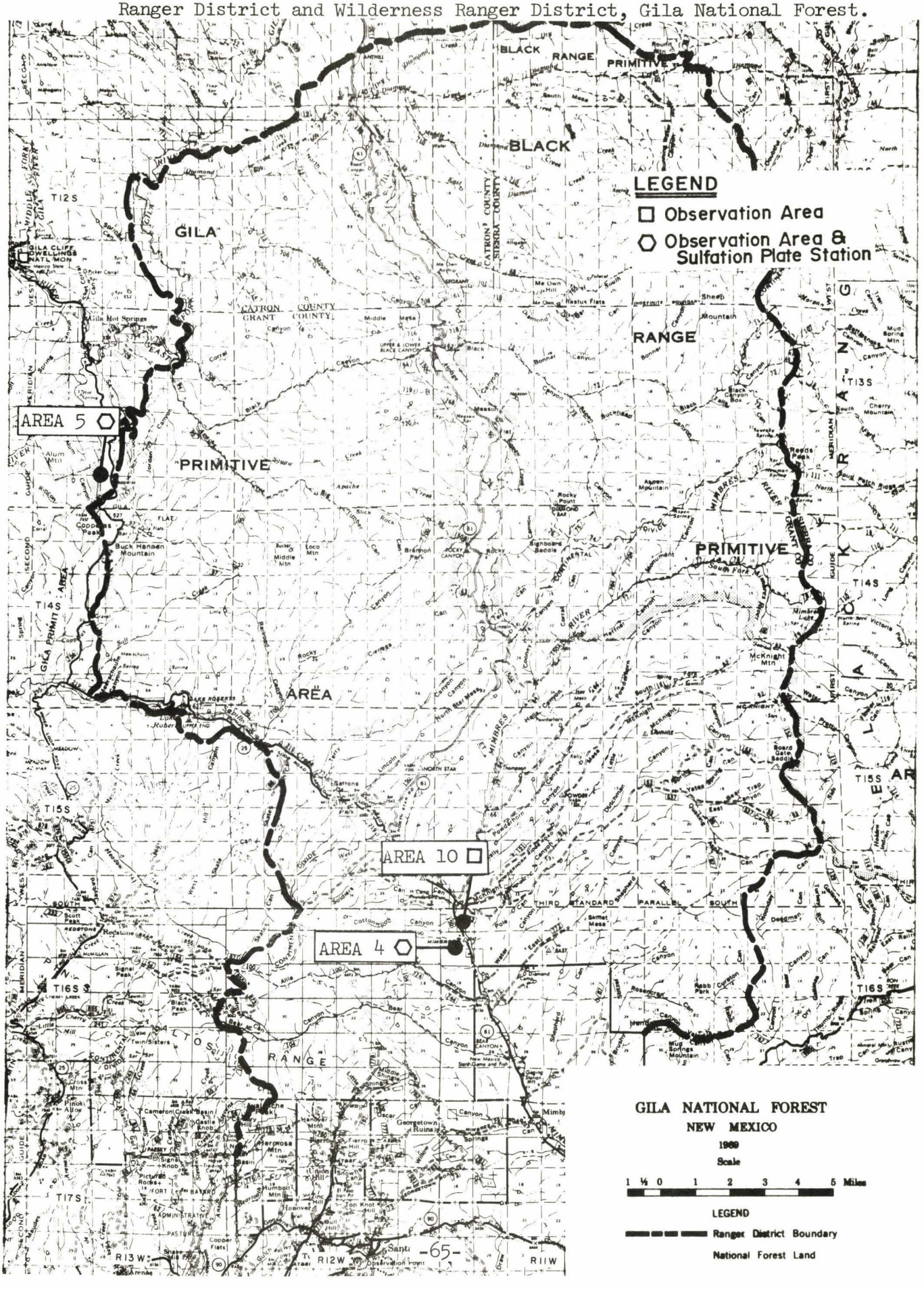
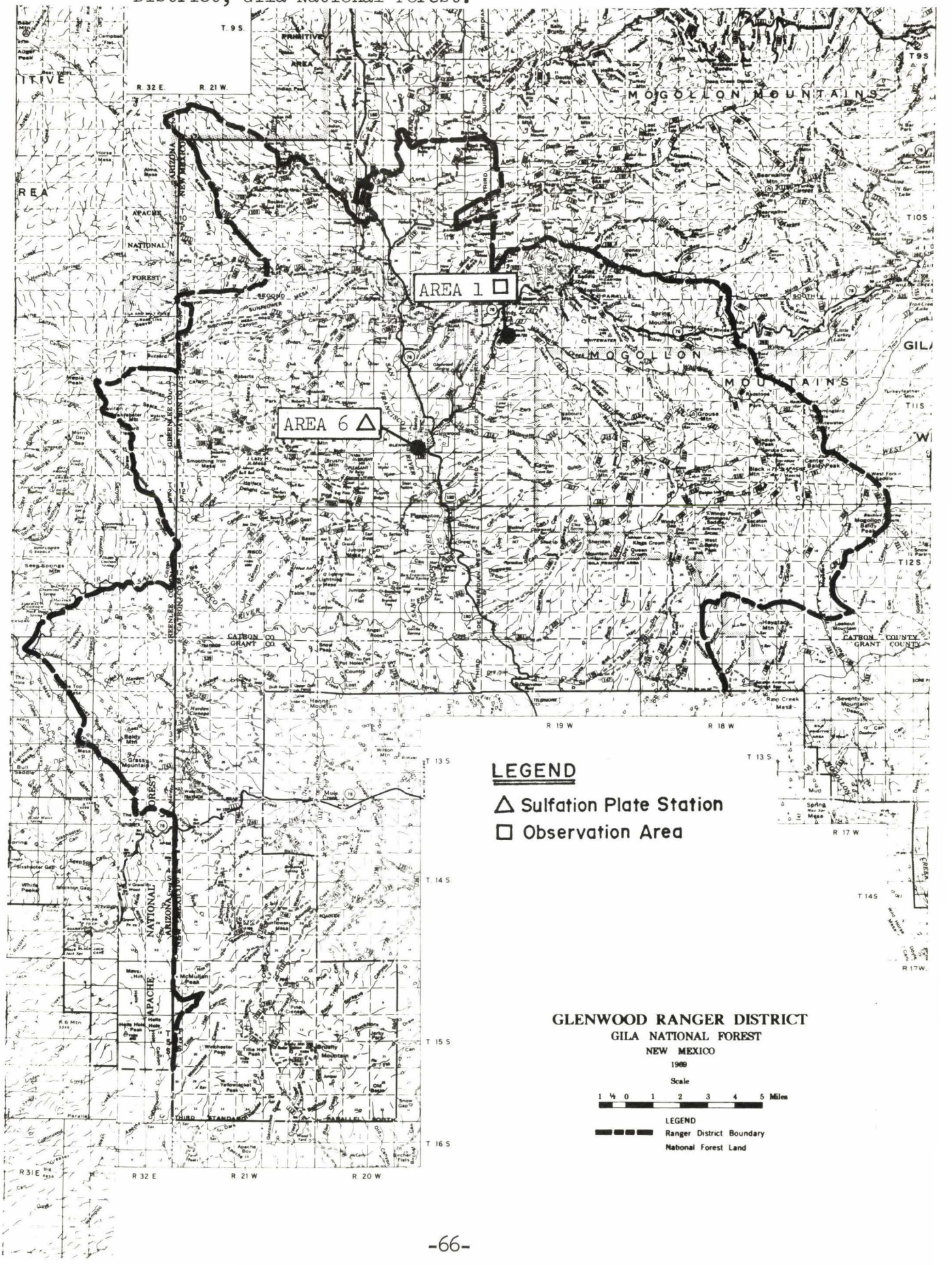


Fig. 32.--Location of sulfation plates and observation areas, Glenwood Ranger District, Gila National Forest.



Group VI.--Santa Catalina Ranger District, Coronado National Forest

The observation areas and sulfation plate stations 1, 2, 6, and 9, on the Santa Catalina Ranger District (Fig. 33), are approximately 7 to 8 miles from the copper smelter at San Manuel, Arizona. The observation area and sulfation plate station 5 is approximately 18 miles from the smelter, but separated from it by a mountain range. These areas were examined in September 1971 and in August 1972.

During the 1971 survey, no symptoms of acute SO_2 injury were found in any of the survey areas. The following leaf and needle markings were noted in the 1971 survey report (11):

1. A needle mottle or fleck on older ponderosa pine needles along the road between area 5 and area 6 (Fig. 6).

2. Symptoms of a leaf spot disease on hackberry, which resembled symptoms caused by SO_2, were noted in area 1.

During the 1972 survey, symptoms of acute SO_2 injury were noted in area 1. In this area, characteristic symptoms of SO_2 injury were noted on brickelbush, willow, and cottonwood (Fig. 34, 35, 36). Brickelbush had a rating of "1/1"; willow and cottonwood both had ratings of "1/2". Tree and plant species which had no symptoms of injury include: cherry, walnut, hackberry, poison ivy, grape, sycamore, and oak.

Area 9 (American Flag Spring) had no definite symptoms of injury; however, foliage symptoms were observed on skunkbush and brickelbush, which may have been caused by SO_2 fumigation. A needle mottle or fleck (Fig. 6) was noted on older ponderosa pine needles in the vicinity of area 5. This needle marking was noted occasionally on current year's needles. Many of the forbs in area 7 were wilted due to drought stress. Ash exhibited symptoms of heat or drought injury (Fig. 37). In this same area, sycamore foliage had a bleached appearance (Fig. 38). This injury has been commonly found on sycamore in several areas of Arizona, and is probably caused by the western lace bug, Corythucha confraterna. Finally, approximately 9 miles of roadside vegetation were examined in area 8. No foliage symptoms were noted which resembled SO_2 injury.

Tree and plant species which were examined included:

Arizona sycamore (Platanus wrightii)
Arizona walnut (Juglans major)
Ash (Fraxinus spp.)
Baccharis (Baccharis spp.)
Box elder (Acer negundo)
Brickelbush (Brickellia spp.)
Catclaw acacia (Acacia spp.)
Cottonwood (Populus spp.)
Desert hackberry (Celtis pallida)
Douglas-fir (Pseudotsuga menziesii)
Grape (Vitis spp.)
Juniper (Juniperus spp.)
Lamb's-quarter (Chenopodium album)
Mesquite (Prosopis juliflora)
Oak (Quercus spp.)
Paloverde (Cercidium spp.)
Ponderosa pine (Pinus ponderosa)
Raspberry (Rubus spp.)
Sacred datura (Datura meteloides)
Saguaro (Cereus giganteus)
Skunkbush (Rhus trilobata)
Sunflower (Helianthus spp.)
Tamarisk (Tamarix gallica)
Western hackberry (Celtis reticulata)
Wild cherry (Prunus spp.)
Willow (Salix spp.)
Yellow bee plant (Cleome lutea)

Sulfation plate data for the period August 1971 to October 1972 are listed in Table 18. Sulfation plate stations 2 and 5 were discontinued in September 1972. With a few exceptions, the monthly average sulfation rates recorded on the Santa Catalina Ranger District were low. It appears, then, that for 1972, fumigations occurred infrequently--high enough over a short period of time to cause injury, but not frequent enough to cause high average monthly sulfation rates. This pattern of infrequent fumigation might partially be explained by a 1970 study conducted by the Arizona Department of Health (20) which suggests that "Pollution channels exist thru which SO_2 diffuses. The most prominent is the Gila River Valley between Hayden and Florence. Others are the San Pedro valley between San Manuel and Redington, and the Gila River valley northeast of Hayden." The San Pedro valley drainage is located to the east of areas 1 and 2, and may account for the low sulfation rates recorded in these areas.

Discussion

One possible explanation for our finding symptoms of SO_2 injury in 1972, and not in 1971, is that the San Manuel smelter has increased its production since September 1971. At present SO_2 emission rates, we expect some injury to occur each summer to sensitive vegetation on the observation areas. Any further increases in SO_2 emissions may increase the severity of plant injury.

Sulfation plate data for this area are inconclusive. The data clearly demonstrate the limitations of sulfation plates in measuring ambient levels of SO_2. In this case, plant injury occurred, but the average monthly sulfation rates were relatively low.

Table 18.--Sulfation plate data, Santa Catalina Ranger District, Coronado National Forest.

Area 1 (Plate 1)

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Aug. 1971	29	** <Detectable minimum
Sep.	23	<Detectable minimum
Oct.	34	1.2
Nov.	29	2.8
Dec.	32	3.4
Jan. 1972	27	8.3
Feb.	32	<Detectable minimum
Mar.	32	<Detectable minimum
Apr.	28	<Detectable minimum
May	31	<Detectable minimum
Jun.	35	<Detectable minimum
Jul.	26	<Detectable minimum
Aug.	30	4.4
Sep.	32	3.8
Oct.	29	5.0
Nov.	34	3.1
Dec.	33	3.1
Jan. 1973	25	<Detectable minimum

Area 1 (Plate 1A)

Aug. 1971	29	<Detectable minimum
Sep.	23	<Detectable minimum
Oct.	34	1.7
Nov.	29	2.8
Dec.	32	5.2
Jan. 1972	27	8.3
Feb.	--	--
Mar.	32	< Detectable minimum
Apr.	28	< Detectable minimum
May	31	< Detectable minimum
Jun.	--	--
Jul.	26	<Detectable minimum
Aug.	29	<Detectable minimum
Sep.	32	3.1
Oct.	29	5.0
Nov.	34	2.0
Dec.	33	4.9
Jan. 1973	25	2.8

Table 18.--Sulfation plate data, Santa Catalina Ranger District, Coronado National Forest (cont'd.).

Area 2

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Aug. 1971	29	** <Detectable minimum
Sep.	23	<Detectable minimum
Oct.	34	1.2
Nov.	29	<Detectable minimum
Dec.	32	<Detectable minimum
Jan. 1972	27	3.0
Feb.	31	<Detectable minimum
Mar.	32	2.3
Apr.	28	2.7
May	31	<Detectable minimum
Jun.	--	--
Jul.	26	<Detectable minimum
Aug.	30	<Detectable minimum
Sep.	32	1.8

Area 5

Aug. 1971	32	<Detectable minimum
Sep.	27	<Detectable minimum
Oct.	29	1.4
Nov.	27	<Detectable minimum
Dec.	35	<Detectable minimum
Jan. 1972	26	3.1
Feb.	32	<Detectable minimum
Mar.	32	<Detectable minimum
Apr.	29	<Detectable minimum
May	31	<Detectable minimum
Jun.	34	<Detectable minimum
Jul.	26	2.4
Aug.	31	<Detectable minimum
Sep.	32	<Detectable minimum

Table 18.--Sulfation plate data, Santa Catalina Ranger District, Coronado National Forest (cont'd.)

Area 6 (Plate 6)

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jun. 1972	25	** <Detectable minimum
Jul.	26	2.4
Aug.	--	--
Sep.	32	1.8
Oct.	29	3.4
Nov.	34	3.1
Dec.	33	<Detectable minimum
Jan. 1973	25	8.3

Area 6 (Plate 6A)

Jun. 1972	25	<Detectable minimum
Jul.	26	3.1
Aug.	30	--
Sep.	32	3.8
Oct.	29	3.4
Nov.	34	13.1
Dec.	33	3.1
Jan. 1973	25	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)

Aug. 1971	- 1.0
Sep. 1971	- 0.8
Oct. 1971-May 1972	- 1.3
Jun. 1972-Jul. 1972	- 1.9
Aug. 1972-Jan. 1973	- 1.3

Fig. 33.--Location of sulfation plates and observation areas, Santa Catalina Ranger District, Coronado National Forest.

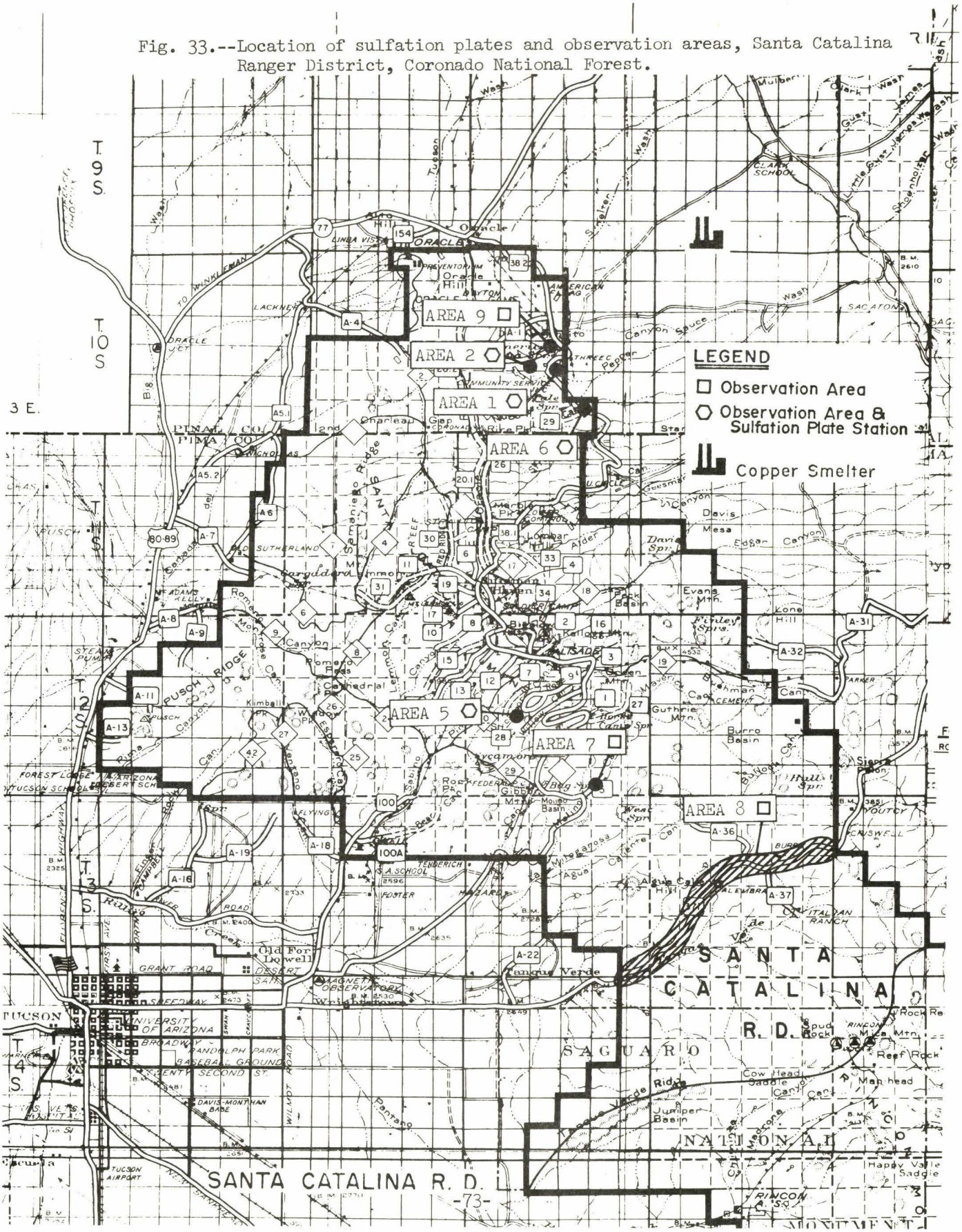


Fig. 34, 35, & 36. – SO_2 injury to brickellbush, willow, and cottonwood, Santa Catalina Ranger District, Aug. 1972.

Fig. 37. – Heat or drought injury to ash, Santa Catalina Ranger District, Aug. 1972.

Fig. 38. – Insect-feeding injury to sycamore, probably caused by the western lace bug, Santa Catalina Ranger District, Aug. 1972.

Group VII.--Clifton Ranger District, Apache National Forest

The observation areas and sulfation plate stations on the Clifton Ranger District are located approximately 2.5 to 20 miles from the copper smelter at Morenci, Arizona (Fig. 39). The observation areas were examined in September 1971 and in August 1972.

During the 1971 survey, no symptoms of SO_2 injury were noted in any of the observation areas on the National Forest; however, typical symptoms of injury were reported on brickelbush, approximately 4 miles from the smelter (Fig. 40). Chlorosis and necrosis of sycamore foliage, and necrotic spots on cherry, were also mentioned in the 1971 survey report (18).

During the 1972 survey, typical symptoms of SO_2 injury were noted on brickelbush in area 5 (Coronado Spring). This species had an injury rating of "1/1". Skunkbush had a few leaf markings similar to symptoms of acute injury, and also had chlorotic foliage. The foliage chlorosis may have been caused by chronic SO_2 injury. Tree and plant species which had no symptoms of acute injury include: walnut, sumac, sycamore, grape, sacred datura, and oak.

Area 4 was inaccessible during the 1972 survey. No plant injury was noted in areas 1, 2, or 3.

Injury to vegetation was noticeable on Highway 666 between areas 3 and 5. A description of plant injury in these areas is presented in Table 19. Symptoms of injury were noted on several species, including: sycamore, cottonwood, skunkbush, willow, sumac, and mesquite (Fig. 41, 42, 43, 44, 45, 46). No tree or plant mortality was observed, even in the areas where severe foliage injury had occurred.

Vegetation was examined along the San Francisco River at several locations between areas 3 and 4. As was noted along Highway 666, many different plant species had symptoms of injury. A description of this injury is presented in Table 20. As might be expected, injury decreased at greater distances from the smelter. An example of possible SO_2 injury to baccharis is shown in Figure 47.

Finally, vegetation was examined west of the smelter between Morenci and Eagle Creek, and along Route 78 at a point approximately 11 miles southeast of the smelter. No injury was noted along Route 78, and little plant injury was noted west of the smelter. The injury which did occur was confined primarily to spicebush, brickelbush, skunkbush, and globe mallow (Fig. 48, 49, 50).

Between areas 1 and 2, several foliage symptoms were noted which are not to be confused with injury caused by SO_2 fumigation. They were: (a) heat or drought injury to brickelbush (Fig. 51); (b) chlorosis of sacred datura (Fig. 52); (c) chlorosis and necrosis of hop-tree foliage (Fig. 53); (d) marginal drying of maple (Fig. 54). Except for the injury to brickelbush, the probable cause of these foliage abnormalities has not been determined. It is our opinion that SO_2 did not cause the injury because (a) the symptoms do not match typical symptoms caused by SO_2; (b) vegetation which appeared to be sensitive to SO_2 in other areas had no symptoms of injury; (c) similar symptoms have been observed on the same species far from known sources of SO_2.

A foliage symptom which is difficult to evaluate is chlorotic foliage. This symptom was noted on sycamore both along Highway 666 where acute SO_2 injury was noted on a variety of plants, and in the vicinity of area 1 where no symptoms of acute SO_2 injury were noted. We have found no way to distinguish the difference between chlorosis caused by chronic SO_2 injury, or chlorosis resulting from other causes.

The following forest trees and plants were examined for symptoms of SO_2 injury:

Arizona sycamore (Platanus wrightii)
Arizona walnut (Juglans major)
Ash (Fraxinus spp.)
Aspen (Populus tremuloides)
Baccharis (Baccharis spp.)
Bee plant (Cleome surrulata)
Box elder (Acer negundo)
Brickelbush (Brickellia spp.)
Buffalo gourd (Cucurbita spp.)
Careless weed (Amaranthus palmeri)
Catclaw acacia (Acacia spp.)
Cockelbur (Xanthium spp.)
Cottonwood (Populus spp.)
Douglas-fir (Pseudotsuga menziesii)
Flannel mullein (Verbascum thapsus)
Globe mallow (Sphaeralcea spp.)
Grape (Vitis spp.)
Hop tree (Ptelea angustifolia)
Jojoba (Simmondsia chinensis)
Juniper (Juniperus spp.)
Mesquite (Prosopis juliflora)
New Mexican locust (Robinia neomexicana)
Pinyon pine (Pinus edulis)
Poison ivy (Toxicodendron radicans)

Ponderosa pine (Pinus ponderosa)
Sacred datura (Datura meteloides)
Skunkbush (Rhus trilobata)
Spicebush (Aloysia wrightii)
Sumac (Rhus spp.)
Sunflower (Helianthus spp.)
Tree of heaven (Ailanthus altissima)
Tree tobacco (Nicotiana glauca)
Western hackberry (Celtis reticulata)
Wild cherry (Prunus spp.)
Willow (Salix spp.)

Sulfation plate data for the period May 1971 to October 1972 are listed in Table 21. Sulfation plate stations at areas 4 and 1 were discontinued in July and November 1972, respectively. Sulfation rates in area 1 are comparable to rates recorded in other areas in the Region far from known sources of SO_2.

The rates recorded in areas 2 and 4 are generally low. There were several months, however, where the rates were comparable to rates recorded in areas where injury was found. The sulfation rates recorded at station 3 are quite high and also are comparable to rates recorded in other areas in the Region where injury was found.

Discussion

Symptoms of SO_2 foliage injury were much more evident near Morenci in 1972 than in 1971. Information from the County Air Pollution Control Office[6/] indicates that a prolonged inversion occurred in early August, and that an unusual fumigation resulted. In addition, the office reports high sulfation rates recorded in August at several of their sulfation plate stations. Our August sulfation rates were not particularly high, perhaps because they were located in areas not affected by the fumigation.

Based on previous survey experience and sulfation plate data, we do not expect to find symptoms of acute SO_2 injury in area 1. The potential for finding injury is higher in areas 2 and 4. Injury may continue to occur between areas 3 and 5, and between 3 and 4. The area surrounding Morenci is quite dry, and the vegetation, other than that growing in moist drainages, is probably resistant to SO_2 injury. The smelter is scheduled to reduce emissions in 1974. This probably will help to reduce plant injury in the Morenci area. Vegetation along Eagle Creek has not been thoroughly examined due to the inaccessibility of the area.

6/ Greenlee County Air Pollution Control Office, P. O. Box 1475, Clifton, Arizona 85533.

Table 19.--SO_2 injury between areas 3 and 5, Clifton Ranger District, Apache National Forest.

Approx. distance from smelter & observation area description	Species	No. plants	Rating and remarks
6.0 miles; 5-chain roadside strip	Sycamore	9	2/3; chlorotic; insect injury noted
	Skunkbush	15	2/3
	Sumac	>50	1/2; one bush had >67% leaves injured
	Brickelbush	>50	1/2
	Catclaw	5	Chlorotic
	Grape	3	No injury
5.0 miles; 5-chain roadside strip	Sycamore	2	Both had >67% of leaves injured; chlorotic
	Willow	2	Both had <33% of leaves injured
	Sumac	2	Both had >67% of leaves injured
	Brickelbush	>50	1/2
	Flannel mullein	8	Chlorotic
	Sacred datura	6	No injury
	Cottonwood	1	<33% of leaves injured
	Tree tobacco	2	Both had <33% of leaves injured
4.5 miles; 7-chain roadside strip	Cottonwood	15	2/3; 15' trees
	Scrub oak	11	1/2
	Brickelbush	>50	1/2
	Flannel mullein	30	Chlorotic
	Tree tobacco	6	No injury
	Sacred datura	4	No injury
	Willow	1	<33% of leaves injured
	Skunkbush	4	3/3
	Sumac	10	2/3
1.0 miles; 5-chain roadside strip	Mesquite	5	2/3
	Hackberry	2	Both trees had <33% of leaves injured
	Tree of heaven	2	1 tree had <33% of leaves injured; 1 tree no injury
	Catclaw	2	2/3
	Sacred datura	1	No injury
	Cottonwood	1	<33% of leaves injured

Table 20.--SO_2 injury between areas 3 and 4, Clifton Ranger District, Apache National Forest.

Approx. distance from smelter & observation area description	Species	No. plants	Rating and remarks
6.0 miles; approx. 1 acre	Cottonwood	8	No injury
	Baccharis	>50	Occasional marking similar to SO_2 injury
	Tree tobacco	>50	No injury
	Hackberry	4	No injury
	Sycamore	1	Symptomatology unclear - severely chlorotic; insect injury, typical symptoms of SO_2 injury
	Brickelbush	1	<33% of leaves injured
5.0 miles; 30 chains along river	Cottonwood	>50	No injury on large trees
	Cottonwood	7	2/3; 15' trees
	Baccharis	>50	2/2
	Tree tobacco	>50	1/1
	Mesquite	10	No injury
	Ash	1	Approx. 50% of leaves injured
4.5 miles; approx. 2 acres	Cottonwood	2	No injury on large trees
	Cottonwood	>50	1/3; 15' trees
	Tree tobacco	20	2/3
	Baccharis	>50	1/1
	Mesquite	>50	No injury
3.0 miles; 8 chains along river	Cottonwood	20	No injury on large trees
	Cottonwood	>50	2/3; 15' trees
	Sunflower	1	60% of leaves injured
	Willow	1	No injury
	Tree tobacco	>50	1/1
2.5 miles; 5 chains along river	Cottonwood	3	Two had no injury; one had >33% leaves injured; large trees
	Cottonwood	>50	2/3; 15' trees
	Mesquite	>50	No injury
	Tree tobacco	6	No injury
	Brickelbush	1	No injury
	Willow	>50	2/3; small saplings
	Skunkbush	4	2/3
	Catclaw	1	No injury

Table 21.--Sulfation plate data, Clifton Ranger District, Apache National Forest.

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Area 1		
May 1971	26	** <Detectable minimum
Jun.	38	<Detectable minimum
Jul.	36	<Detectable minimum
Aug.	22	--
Sep.	32	1.8
Oct.	44	<Detectable minimum
Nov.	27	<Detectable minimum
Dec.-Jan. 1972	37	3.6
Jan.-Feb.	25	3.2
Feb.-Mar.	30	<Detectable minimum
Mar.-Apr.	42	<Detectable minimum
May-Jun.	51	<Detectable minimum
Jun.	18	<Detectable minimum
Jul.	31	<Detectable minimum
Aug.	28	2.9
Sep.	31	1.9
Oct.	28	<Detectable minimum
Area 2		
May 1971	29	3.8
Jun.	35	6.4
Jul.	29	1.6
Aug.	29	7.6
Sep.	32	<Detectable minimum
Oct.	44	4.7
Nov.	26	2.2
Dec.	45	4.9
Jan. 1972	18	2.2
Feb.	29	2.0
Mar.	27	4.3
Apr.	23	10.1
May	26	<Detectable minimum
Jun.	35	<Detectable minimum
Jul.	31	<Detectable minimum
Aug.	26	3.1
Sep.	34	4.2
Oct.	28	7.8
Nov.	37	5.1
Dec.	37	2.8
Jan. 1973	31	5.2

Table 21.--Sulfation plate data, Clifton Ranger District, Apache National Forest (cont'd.).

Area 3 (Plate 1)

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
May 1971	30	8.5
Jun.	36	14.3
Jul.	25	** <Detectable minimum
Aug.	40	3.8
Sep.	26	<Detectable minimum
Oct.	46	9.4
Nov.	24	3.4
Dec.	39	7.0
Jan. 1972	23	5.0
Feb.	31	9.3
Mar.	17	10.2
Apr.	36	8.2
May	23	7.5
Jun.	34	7.1
Jul.	30	<Detectable minimum
Aug.	24	2.6
Sep.	39	3.7
Oct.	25	4.8
Nov.	34	9.5
Dec.	35	5.4
Jan. 1973	28	9.7

Area 3 (Plate 1A)

Sep. 1971	26	<Detectable minimum
Oct.	46	6.1
Nov.	24	<Detectable minimum
Dec.	39	8.2
Jan. 1972	23	6.3
Feb.	31	10.3
Mar.	17	3.4
Apr.	36	9.9
May	23	<Detectable minimum
Jun.	34	4.4
Jul.	30	<Detectable minimum
Aug.	26	3.1
Sep.	39	5.0
Oct.	25	3.9
Nov.	34	11.9
Dec.	35	8.9
Jan. 1973	28	15.3

Table 21.--Sulfation plate data, Clifton Ranger District, Apache National Forest (cont'd.).

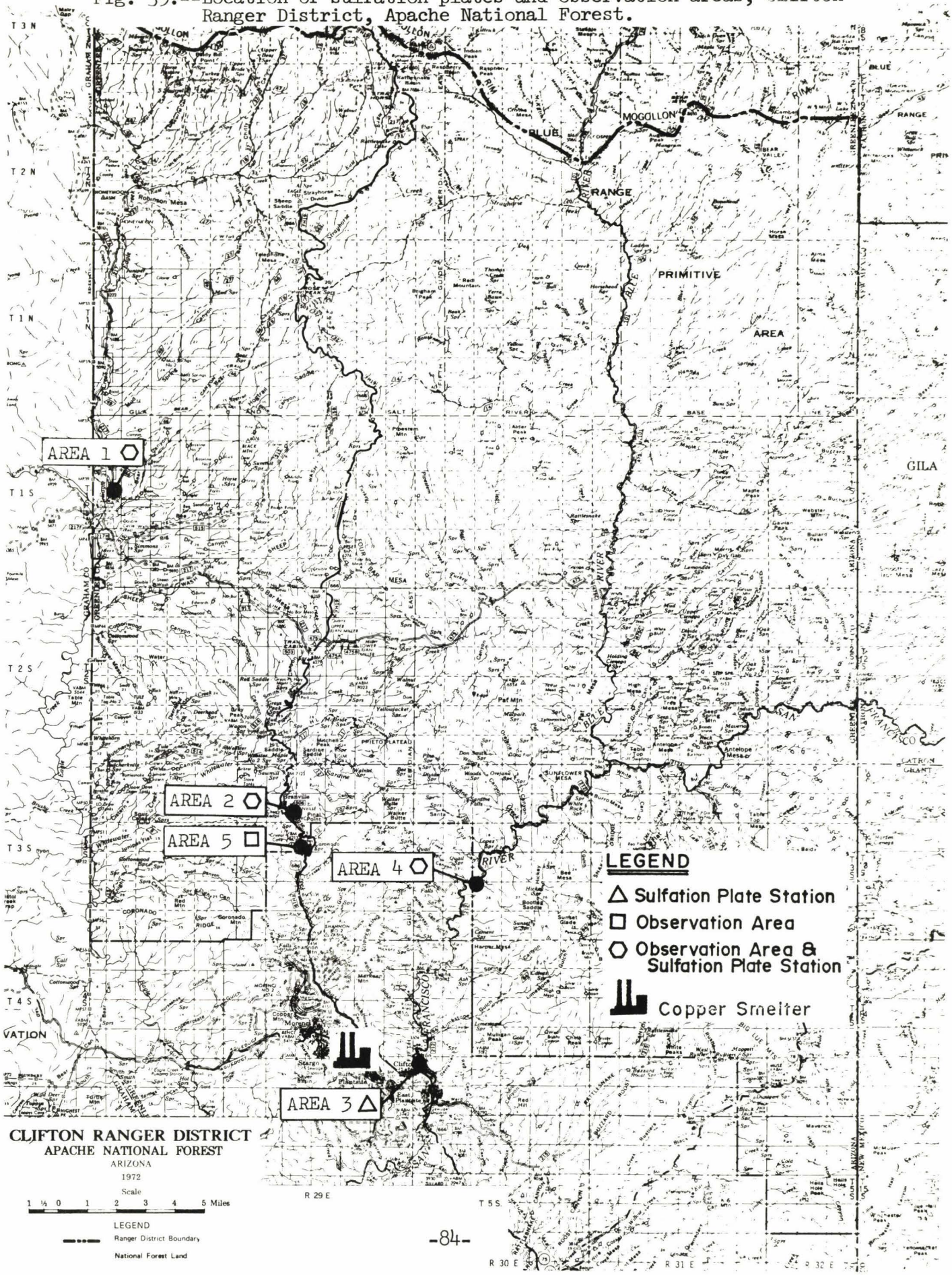
Area 4

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
May 1971	28	** <Detectable minimum
Jun.	33	7.2
Jul.	23	<Detectable minimum
Aug.	42	2.6
Sep.-Feb. 1972	Sulfation plate inaccessible due to road washout	
Mar.-Apr.	47	7.0
May	26	<Detectable minimum
Jun.	41	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
May 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972-Jan. 1973 - 1.3

Fig. 39.--Location of sulfation plates and observation areas, Clifton Ranger District, Apache National Forest.



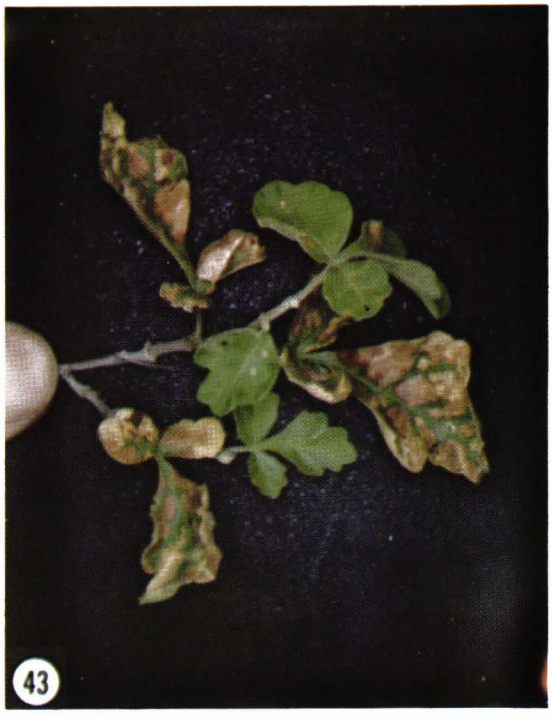


Fig. 40. – SO_2 injury to brickellbush, Morenci, Arizona, Sep. 1971.

Fig. 41, 42, & 43. – SO_2 injury to sycamore, cottonwood, and skunkbush, Morenci, Arizona, Aug. 1972.

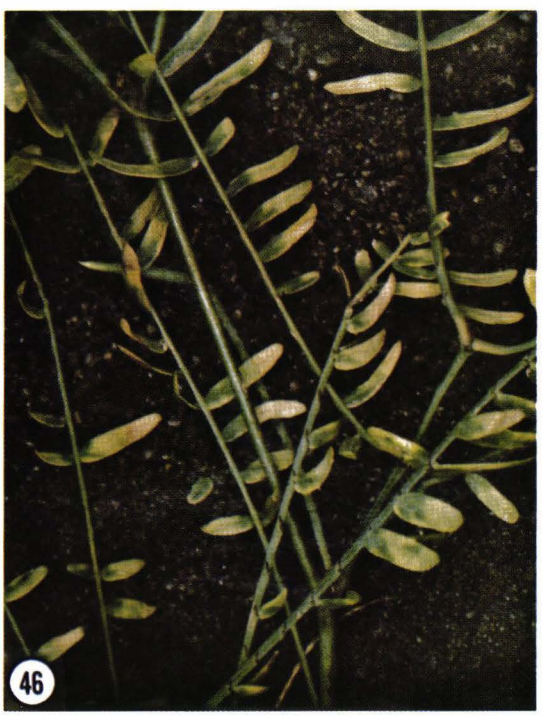


Fig. 44 & 45. – SO_2 injury to willow and sumac, Morenci, Arizona, Aug. 1972.
Fig. 46 & 47. – Probable SO_2 injury to mesquite and baccharis, Morenci, Arizona, Aug. 1972.

Fig. 48, 49, & 50. – SO_2 injury to brickellbush, skunkbush, and globe mallow, Morenci, Arizona, Aug. 1972.

Fig. 51. – Heat or drought injury to brickellbush, Morenci, Arizona, Aug. 1972.

Fig. 52, 53, & 54. – Foliage abnormalities of causes other than SO_2 to sacred datura, hop tree, and maple. Clifton Ranger District, Aug. 1972.

Group VIII.--Tonto National Monument; Sierra Ancha Experimental Forest; Globe Ranger District, Tonto National Forest; Roosevelt Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest

Tonto National Monument

The observation area and sulfation plate station on the Tonto National Monument are located approximately 22 miles from the copper smelter near Miami, Arizona (Fig. 55). This area was examined in September 1971 and in September 1972.

During the 1971 survey, no symptoms of SO_2 injury were noted on the National Monument. Bleached sycamore foliage caused by insect feeding, a leaf spot on hackberry, cold injury to saguaro cactus, and drought injury to jojoba were noted in the 1971 survey report (10). No symptoms of SO_2 injury were noted during the 1972 survey.

The observation area on the Tonto National Monument is located in a small area of mesic, deciduous forest in the Cave Canyon drainage. This area burned in July 1970. The most obvious signs of the fire are several dead or injured sycamore trees.

Trees and plants which were examined for symptoms of SO_2 injury included the following:

Arizona sycamore (*Platanus wrightii*)
Arizona walnut (*Juglans major*)
Brickelbush (*Brickellia* spp.)
Desert hackberry (*Celtis pallida*)
Globe mallow (*Sphaeralcea* spp.)
Jojoba (*Simmondsia chinensis*)
Juniper (*Juniperus* spp.)
Saguaro (*Cereus giganteus*)
Skunkbush (*Rhus trilobata*)

Sulfation plate data for the period July 1971 to August 1972 are listed in Table 22. These rates are comparable to rates recorded in areas far from known sources of SO_2. This sulfation plate station was discontinued in September 1972.

Sierra Ancha Experimental Forest; Globe Ranger District, Tonto National Forest; Roosevelt Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest

A detection system, consisting of 10 sulfation plate stations and 11 observation areas, was established in 1971 and 1972 (Fig. 55, 56). The sulfation plate stations and observation areas are located on the Sierra Ancha Experimental Forest (area 14); the Globe Ranger District (areas 4, 5, 6, 7, 10); the recently combined Tonto Basin and Roosevelt Ranger Districts (areas 1, 2, 3, 8, 11, 12, 13); and on the W. Bohme Ranch (area 9). These areas are located 2 to 40 miles from the smelter near Miami. The smelters at Hayden are approximately 20 miles from the nearest observation area (area 5). The observation areas were examined in October 1971 and in September 1972.

The following observations were noted in the 1971 survey report (19):

1. Symptoms of acute SO_2 injury were noted in area 6 on brickelbush and thoroughwort. Leaf markings were also noted on sycamore; however, these markings were not clearly typical of SO_2 injury. A chlorotic mottle or fleck of unknown cause was noted on the older ponderosa pine needles in area 6 (Fig. 6). This needle marking was noted occasionally on the current year's needles. Other plants examined in the area appeared to have normal foliage.

2. Symptoms of chronic and acute SO_2 injury were noted on a variety of tree and plant species in area 9. Injury was noted on tree tobacco, skunkbush, ash, Arizona walnut, mesquite, cottonwood, Mexican elder, hackberry, and desert tobacco. The needles of several pinyon pine trees had some tip burn; however, this symptom was not found consistently in the area.

3. The foliage of several Arizona walnut trees in area 11 had leaf markings similar to symptoms of SO_2 injury. These markings were probably not caused by SO_2 because vegetation which appeared sensitive to SO_2 in other areas had no symptoms of injury.

4. The foliage of forest trees and associated plants in all other observation areas appeared normal.

During the 1972 survey, the following was noted:

1. Symptoms of acute SO_2 injury were noted in area 6 on sycamore, willow, and brickelbush (Fig. 57, 58, 59). Leaf markings were also noted on cherry and skunkbush (Fig. 60, 61). These markings may have been caused by SO_2; however, they are not clearly typical of acute SO_2 injury. During an earlier visit to area 6, in April 1972, symptoms of SO_2 injury were noted on skunkbush, sycamore, and

lupine, but not on brickelbush. Ponderosa pine growing in area 6 had no obvious symptoms of acute SO_2 injury. A chlorotic fleck of unknown cause was noted on older ponderosa pine needles in this area (Fig. 6). These trees appeared to have a full complement of needles. A description of plant injury in area 6 is presented in Table 23.

2. Symptoms of acute SO_2 injury were noted on brickelbush (Fig. 62) in area 10. In addition, leaf markings were noted on poison ivy (Fig. 63, 64) which may be symptomatic of chronic injury. Care should be taken in evaluating this symptom because a somewhat similar marking was noted in area 14--an area approximately 30 miles from the smelter. A description of plant injury in area 10 is presented in Table 24.

3. Symptoms of acute SO_2 injury were noted on a wide variety of vegetation in area 9. Trees and plants which had symptoms of foliage injury include black walnut, bee plant, tree tobacco, cottonwood, skunkbush, sacred datura, brickelbush, and desert tobacco (Fig. 65, 66, 67, 68, 69, 70, 71, 72). Some needle tip burn was noted on pinyon pine (Fig. 73). This symptom may have been caused by SO_2 fumigation; however, this particular symptom can also be caused by other diseases or environmental stress. Leaf chlorosis of sacred datura (Fig. 74) was noted. This symptom is similar to the symptoms caused by SO_2 fumigation, but has been found in areas far from sources of SO_2. A description of plant injury in area 9 is presented in Table 25.

4. No symptoms of SO_2 injury were noted in any of the other observation areas. In area 11, leaf spot symptoms which resemble SO_2 injury were again noted on walnut (Fig. 75). Possible SO_2 injury to these trees was ruled out for the reasons discussed previously.

Tree and plants which were examined for symptoms of SO_2 injury include:

Alligator juniper (Juniperus deppeana)
Arizona alder (Alnus oblongifolia)
Arizona sycamore (Platanus wrightii)
Arizona walnut (Juglans major)
Arizona white oak (Quercus arizonica)
Ash (Fraxinus spp.)
Baccharis (Baccharis spp.)
Bee plant (Cleome serrulata)
Box elder (Acer negundo)
Brickelbush (Brickellia spp.)
Cottonwood (Populus spp.)
Desert hackberry (Celtis pallida)
Emory oak (Quercus emoryi)
Gambel oak (Quercus gambelii)

Globe mallow (Sphaeralcea spp.)
Golden crownbeard (Verbesina encelioides)
Grape (Vitis spp.)
Lamb's-quarter (Chenopodium album)
Manzanita (Arctostaphylos spp.)
Maple (Acer spp.)
Mesquite (Prosopis juliflora)
Mexican elder (Sambucus mexicana)
New Mexican locust (Robinia neomexicana)
Pinyon pine (Pinus edulis)
Poison ivy (Toxicodendron radicans)
Ponderosa pine (Pinus ponderosa)
Sacred datura (Datura meteloides)
Serviceberry (Amelanchier spp.)
Shrub live oak (Quercus turbinella)
Skunkbush (Rhus trilobata)
Thoroughwort (Eupatorium herbaceum)
Tree tobacco (Nicotiana glauca)
Wild cherry (Prunus spp.)
Willow (Salix spp.)

Sulfation plate data for the period July 1971 to October 1972 are presented in Table 26. High sulfation rates were recorded in areas 1, 6, and 9. Plant injury was noted in areas 6 and 9, but not in area 1. This might be expected because area 1 is on a very dry site, and vegetation growing in this area is probably resistant to SO_2 injury. The sulfation rates recorded in the other areas are comparable to rates recorded in areas far from known sources of SO_2.

All sulfation plate stations were discontinued in October 1972, except for those in areas 6 and 9.

Discussion

Symptoms of foliage injury to a variety of trees and other plants were noted both in 1971 and 1972 in the vicinity of the copper smelter near Miami, Arizona. Even though symptoms of injury were noted, no dead or severely declining trees were observed in the observation areas. In 1974, the smelter is scheduled to decrease SO_2 emissions to almost one-tenth of its present level. This should greatly decrease symptoms of injury in the area.

Table 22.--Sulfation plate data, Tonto National Monument

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	31	** <Detectable minimum
Aug.	37	3.0
Sep.	30	1.3
Oct.	31	1.3
Nov.	31	<Detectable minimum
Dec.	34	<Detectable minimum
Jan. 1972	27	<Detectable minimum
Feb.	29	2.0
Mar.	31	<Detectable minimum
Apr.	30	2.5
May	31	<Detectable minimum
Jun.	30	<Detectable minimum
Jul.	32	<Detectable minimum
Aug.	34	2.4

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Jul. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972 - 1.3

Table 23.--SO_2 injury in area 6, Globe Ranger District, Tonto National Forest.

Approx. distance from smelter & observation area description	Species	No. plants	Rating and remarks
4 miles; approx. 2 acres	Sycamore	2	Both had >67% of leaves injured; leaves chlorotic
	Willow	1	>67% of leaves injured
	Cottonwood	1	Approx. 25% of leaves injured
	Brickelbush	Approx. 25	1/2
	Oak	--	No injury
	Skunkbush	>50	1/1; also had chlorotic mottle
	Cherry	1	Chlorotic, with small amount of foliage necrosis
	Juniper	--	No injury
	Manzanita	>50	No injury
	Ponderosa pine	>50	Needle fleck on older needles; have normal complement of needles
	Mesquite	--	No injury
	Grape	5	No injury

Table 24.--SO_2 injury in area 10, Globe Ranger District, Tonto National Forest.

Approx. distance from smelter & observation area description	Species	No. plants	Rating and remarks
6 miles from smelter; 10 chains along stream bed	Brickelbush	>50	1/3; have typical symptoms
	Poison ivy	>50	Symptoms of unknown cause - may be SO_2-related
	Sycamore	25	Chlorosis; necrosis; symptoms not typical of acute SO_2 injury
	Arizona alder	>50	Symptoms of injury negligible; only a few leaves with typical symptoms
	Skunkbush	13	Chlorosis; necrosis; symptoms not typical of acute SO_2 injury

Table 25.--SO_2 injury in area 9, W. Bhome Ranch.

Approx. distance from smelter & observation area description	Species	No. plants	Rating and remarks
2 miles; approx. 5 acres	Golden crownbeard	>50	1/1
	Tree tobacco	>50	1/3
	Desert tobacco	>50	1/3
	Brickelbush	>50	2/3
	Bee plant	30	1/3
	Ash		
	- saplings	1	Typical symptoms present.
	- large	2	No foliage symptoms.
	Cottonwood		
	- saplings	23	1/3
	- large	7	One had symptoms of injury. Chlorosis, insect injury, and necrotic areas not typical of SO_2 injury were noted on other trees.
	Black walnut	1	Symptoms of SO_2 injury noted.
	Oak	>50	No injury.
	Mesquite	>50	Chlorosis.
	Serviceberry	9	Older leaves had no injury; young leaves had some symptoms of injury.
	Skunkbush	27	Chlorotic - no acute symptoms.
	Pinyon pine	7	Some needle burn on one tree.
	Juniper	15	No symptoms of injury.
	Grape	3	Chlorotic, with marginal necrosis.

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest.

Area 1 (Plate 1) - Roosevelt Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	31	** <Detectable minimum
Aug.	33	1.4
Sep.	32	1.3
Oct.	30	7.3
Nov.-Dec.	46	10.3
Dec.-Jan. 1972	42	20.1
Jan.-Feb.	46	6.9
Mar.	22	<Detectable minimum
Apr.	35	<Detectable minimum
May	27	4.3
Jun.	28	3.5
Jul.-Aug.	56	1.7

Area 1 (Plate 1A) - Roosevelt Ranger District

Jul. 1971	31	2.8
Aug.	33	<Detectable minimum
Sep.	32	1.3
Oct.	30	6.0
Nov.-Dec.	46	8.3
Dec.-Jan. 1972	42	15.1
Jan.-Feb.	46	6.8
Mar.	22	<Detectable minimum
Apr.	35	2.1
May	27	6.4
Jun.	28	<Detectable minimum
Jul.-Aug.	56	3.8

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.).

Area 2 (Plate 2) - Roosevelt Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	31	2.8
Aug.	33	** <Detectable minimum
Sep.	32	<Detectable minimum
Oct.	30	1.3
Nov.	33	<Detectable minimum
Dec.	--	--
Jan. 1972	27	<Detectable minimum
Feb.-Mar.	46	<Detectable minimum
Mar.	22	<Detectable minimum
Apr.	35	<Detectable minimum
May	27	6.4
Jun.	28	<Detectable minimum
Jul.-Aug.	56	1.1

Area 2 (Plate 2A) - Roosevelt Ranger District

Jul. 1971	31	1.5
Aug.	33	<Detectable minimum
Sep.	32	<Detectable minimum
Oct.	30	1.3
Nov.	33	<Detectable minimum
Dec.	--	--
Jan. 1972	27	<Detectable minimum
Feb.-Mar.	46	<Detectable minimum
Mar.	22	<Detectable minimum
Apr.	35	<Detectable minimum
May	27	<Detectable minimum
Jun.	28	<Detectable minimum
Jul.-Aug.	56	1.4

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.)

Area 3 - Roosevelt Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	31	3.5
Aug.	33	** <Detectable minimum
Sep.	32	<Detectable minimum
Oct.	36	<Detectable minimum
Nov.-Dec.	40	<Detectable minimum
Dec.-Mar. 1972	88	2.1
Mar.	22	<Detectable minimum
Apr.	35	<Detectable minimum
May	27	<Detectable minimum
Jun.	28	<Detectable minimum
Jul.-Aug.	56	1.1

Area 4 (Plate 4) - Globe Ranger District

Jul. 1971	32	<Detectable minimum
Aug.	30	2.9
Sep.	34	2.4
Oct.	27	1.5
Nov.	30	<Detectable minimum
Dec.	33	<Detectable minimum
Jan. 1972	29	<Detectable minimum
Feb.	28	<Detectable minimum
Mar.	34	2.9
Apr.	27	<Detectable minimum
May	35	<Detectable minimum
Jun.	22	<Detectable minimum
Jul.	36	<Detectable minimum
Aug.	31	<Detectable minimum
Sep.	31	<Detectable minimum
Oct.	29	2.0

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.).

Area 4 (Plate 4A) - Globe Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	32	2.7
Aug.	30	1.5
Sep.	34	** <Detectable minimum
Oct.	27	1.5
Nov.	30	<Detectable minimum
Dec.	33	<Detectable minimum
Jan. 1972	29	6.8
Feb.	28	<Detectable minimum
Mar.	--	--
Apr.	27	<Detectable minimum
May	35	<Detectable minimum
Jun.	22	<Detectable minimum
Jul.	36	<Detectable minimum
Aug.	31	2.0
Sep.	31	3.2
Oct.	29	3.4

Area 5 - Globe Ranger District

Jul. 1971	32	<Detectable minimum
Aug.	30	2.9
Sep.	34	<Detectable minimum
Oct.	27	<Detectable minimum
Nov.	30	<Detectable minimum
Dec.	33	<Detectable minimum
Jan. 1972	29	3.4
Feb.	29	<Detectable minimum
Mar.	33	3.5
Apr.	27	<Detectable minimum
May	35	<Detectable minimum
Jun.	22	<Detectable minimum
Jul.	36	<Detectable minimum
Aug.	31	2.0
Sep.	31	<Detectable minimum
Oct.	29	2.0

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.).

Area 6 - Globe Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	32	** < Detectable minimum
Aug.	30	4.4
Sep.	34	6.8
Oct.	27	4.1
Nov.	30	4.8
Dec.	33	5.4
Jan. 1972	29	10.8
Feb.	29	9.6
Mar.	33	3.5
Apr.	27	3.6
May	35	3.3
Jun.	23	< Detectable minimum
Jul.	35	3.5
Aug.	31	3.0
Sep.	31	6.3
Oct.	30	7.3
Nov.	30	5.4
Dec.	28	6.8
Jan. 1973	34	5.6

Area 7 - Globe Ranger District

Jul. 1971	32	< Detectable minimum
Aug.	30	4.4
Sep.	34	1.2
Oct.	27	< Detectable minimum
Nov.	30	< Detectable minimum
Dec.	33	< Detectable minimum
Jan. 1972	29	5.8
Feb.	29	2.6
Mar.	33	3.5
Apr.	27	< Detectable minimum
May	35	< Detectable minimum
Jun.	23	< Detectable minimum
Jul.-Aug.	--	--
Sep.	31	< Detectable minimum
Oct.	29	3.4

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.).

Area 8 - Tonto Basin Ranger District

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Jul. 1971	31	** < Detectable minimum
Aug.	29	4.6
Sep.	30	< Detectable minimum
Oct.	27	< Detectable minimum
Nov.	33	< Detectable minimum
Dec.	35	< Detectable minimum
Jan. 1972	22	2.6
Feb.	34	< Detectable minimum
Mar.	26	< Detectable minimum
Apr.	30	< Detectable minimum
May	35	3.3
Jun.	26	< Detectable minimum
Jul.	30	< Detectable minimum
Aug.	33	< Detectable minimum
Sep.	29	< Detectable minimum
Oct.	30	1.9

Area 9 (Plate 9) - W. Bhome Ranch

Apr. 1971	27	3.6
May	35	3.3
Jun.	23	6.5
Jul.	35	4.5
Aug.	31	7.3
Sep.	31	11.9
Oct.	30	10.0
Nov.	30	14.3
Dec.	--	--
Jan. 1972	34	14.1

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.).

Area 9 (Plate 9A) - W. Bhome Ranch

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Apr. 1971	27	** < Detectable minimum
May	35	< Detectable minimum
Jun.	23	8.0
Jul.	35	3.8
Aug.	31	8.4
Sep.	31	12.5
Oct.	30	9.4
Nov.	30	15.2
Dec.	28	13.4
Jan. 1972	34	16.2

Area 9 (Plate 9B) - W. Bhome Ranch

Apr. 1971	27	<Detectable minimum
May	35	4.3
Jun.	23	8.0
Jul.	35	4.8
Aug.	31	7.3
Sep.	31	12.5
Oct.	30	9.4
Nov.	30	15.6
Dec.	28	13.8
Jan. 1972	34	15.1

Table 26.--Sulfation plate data; Roosevelt Ranger District, Tonto National Forest; Globe Ranger District, Tonto National Forest; Tonto Basin Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest (cont'd.).

Area 14 - Sierra Ancha Experimental Forest

Month	Days exposed	* Sulfation rate (Micrograms $SO_3/cm^2/day$)
Sep. 1971	34	** <Detectable minimum
Oct.	28	<Detectable minimum
Nov.	29	<Detectable minimum
Dec.	34	<Detectable minimum
Jan. 1972	28	<Detectable minimum
Feb.	29	<Detectable minimum
Mar.	33	<Detectable minimum
Apr.	28	<Detectable minimum
May	36	5.5
Jun.	29	<Detectable minimum
Jul.	27	<Detectable minimum
Aug.	29	2.2
Sep.	35	<Detectable minimum
Oct.	34	<Detectable minimum

*Corning Laboratories, Inc., Cedar Falls, Iowa, supplies and analyzes all sulfation plates.

**Detectable minimum for 30-day period (micrograms $SO_3/cm^2/day$)
Apr. 1971-Aug. 1971 - 1.0
Sep. 1971 - 0.8
Oct. 1971-May 1972 - 1.3
Jun. 1972-Jul. 1972 - 1.9
Aug. 1972-Jan. 1973 - 1.3

Fig. 55.--Location of sulfation plates and observation areas, Globe Ranger District, Tonto National Forest; Roosevelt Ranger District, Tonto National Forest; Sierra Ancha Experimental Forest; Tonto National Monument.

Fig. 56.--Location of sulfation plates and observation areas, Tonto Basin Ranger District, Tonto National Forest.

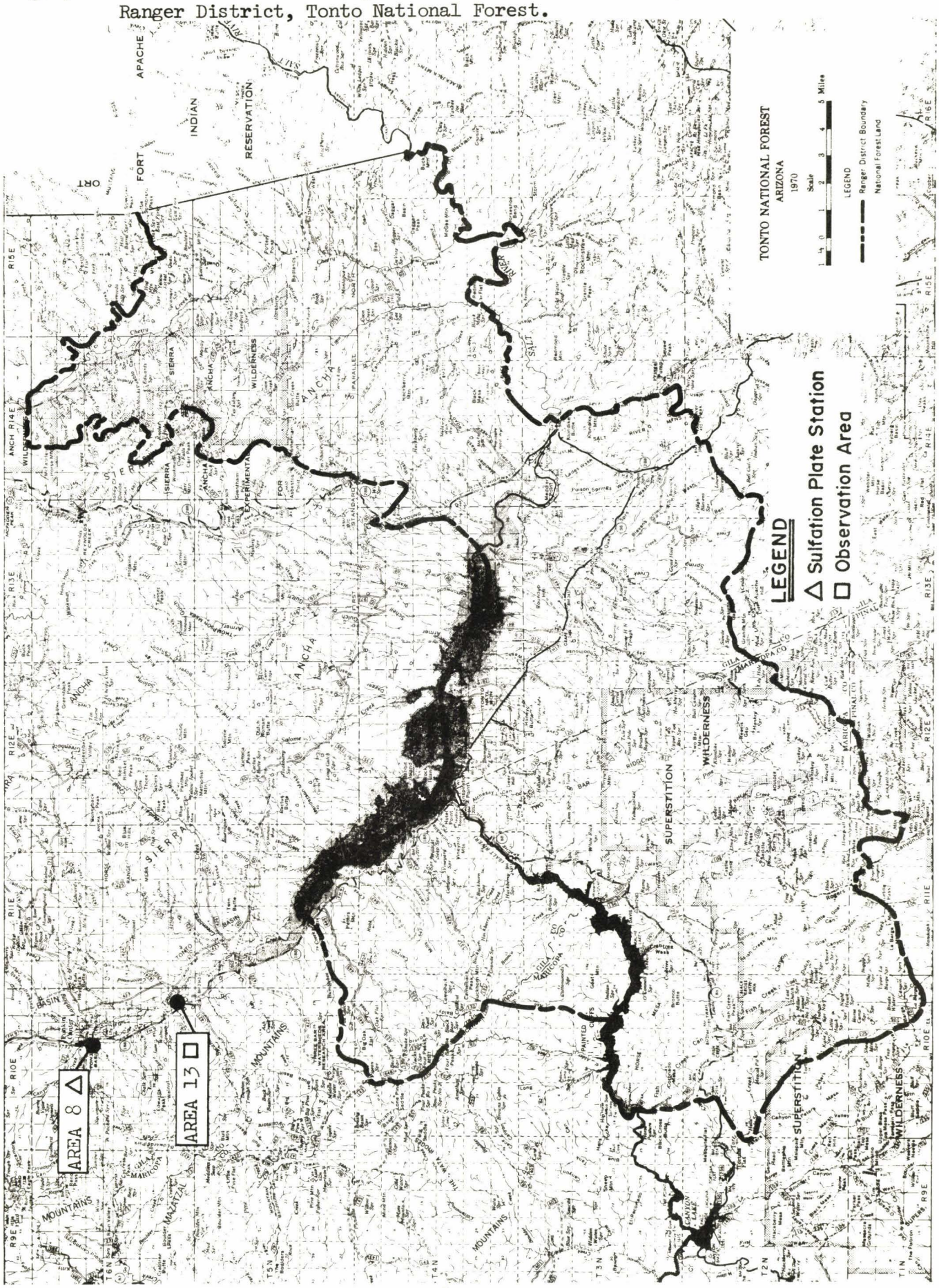


Fig. 57, 58, & 59. – SO_2 injury to sycamore, willow, and brickellbush, Globe Ranger District, Sep. 1972.

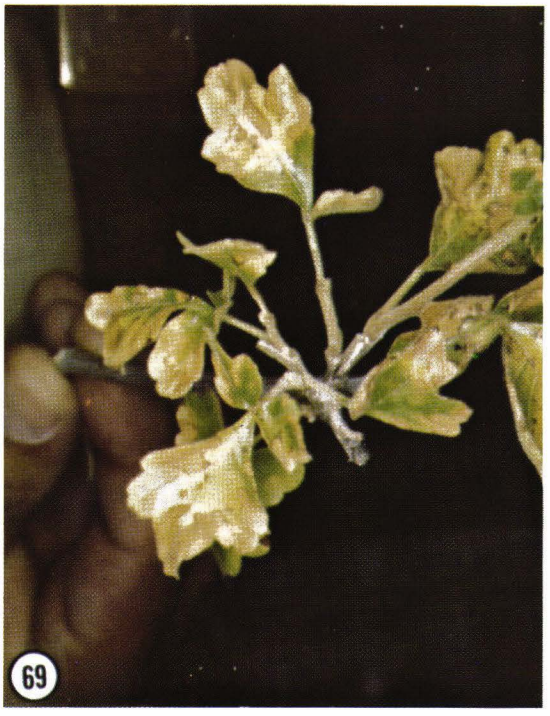
Fig. 60. – Symptoms resembling SO_2 injury to cherry, Globe Ranger District, Sep. 1972.

Fig. 61. – Possible symptoms of chronic SO_2 injury to skunkbush, Globe Ranger District, Sep. 1972.

Fig. 62. – SO_2 injury to brickellbush, Globe Ranger District, Sep. 1972.

Fig. 63 & 64. – Possible symptoms of chronic SO_2 injury to poison ivy, Globe Ranger District, Sep. 1972.

Fig. 65, 66, 67, & 68. – SO_2 injury to black walnut, bee plant, tree tobacco, and cottonwood, Bohme Ranch, Sep. 1972.



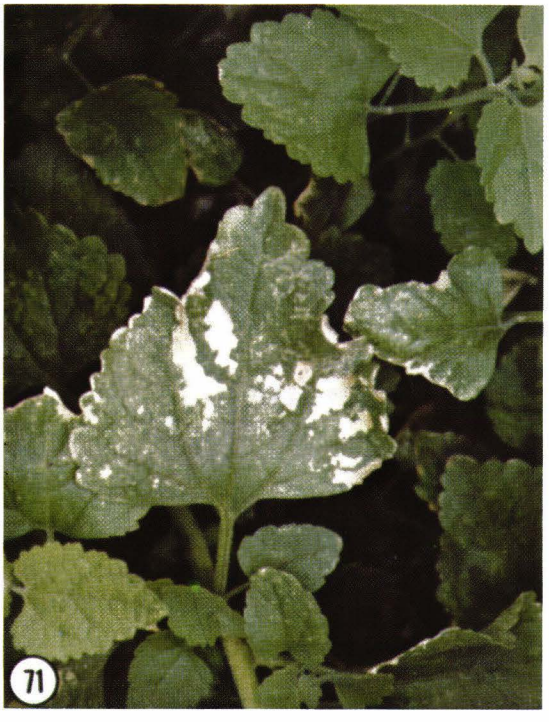


Fig. 69, 70, 71, & 72. – SO_2 injury to skunkbush, sacred datura, brickellbush, and desert tobacco, Bhome Ranch, Sep. 1972.

Fig. 73. – Needle tip burn, pinyon pine, of undetermined cause, Bhome Ranch, Sep. 1972.

Fig. 74. – Chlorosis of undetermined cause, of sacred datura, Bhome Ranch, Sep. 1972.

Fig. 75. – A black walnut leaf spot of undetermined cause, Roosevelt Ranger District, Sep. 1972.

Sulfation Plate Reliability

In order to get some idea of sulfation plate reliability, duplicate plates[7] were exposed in eight locations in New Mexico and Arizona. For analysis purposes, only plate-pairs which had at least one positive reading were considered. Plates which had readings of less than the detectable minimum were considered to have a reading of zero. The average difference between the sulfation rates was 1.9. The range of differences was from 0 to 10. When all plate-pairs are considered, there is no significant difference between the average of the means of the plate-pairs ($t = .041$ with 92 degrees of freedom). There is a significant linear regression correlation between the sulfation rates of each set of plate-pairs ($r = .813$ with 92 degrees of freedom).

Thus, the sulfation plates appear to be reliable enough to provide an economical way of determining general information about the average monthly dispersion of sulfur compounds in an area. They do not provide information concerning specific SO_2 concentrations or duration of individual fumigations.

SUMMARY

The survey was designed to detect acute SO_2 foliage injury to forest vegetation. Chronic injury was considered; however, we found no reliable method for identifying this type of injury. Other related problems, such as the effect of other pollutants, synergistic effects of pollutants, the so-called "invisible injury" effect, and long-term ecological effects, were not investigated.

Symptoms of acute SO_2 injury were found on the Tonto National Forest, near Miami, Arizona; on the Coronado National Forest, near San Manuel, Arizona; and on the Apache National Forest, near Morenci, Arizona. In addition, symptoms which resembled SO_2 injury, but need further evaluation, were noted near Hurley, New Mexico. No areas were found where trees were being killed by SO_2 fumigation. Interpreting the significance of foliage injury is difficult. We do not know the immediate and long-term effects of foliage injury on forest plant condition.

The needle fleck (Fig. 6), which was reported primarily on ponderosa pine, but reported also on Apache and Chihuahua pine, was noted virtually throughout the ponderosa pine type in the Region. During the summer months, it was commonly found on the older needles, and was only occasionally found on the current needles. This marking superficially

[7] Where duplicate plates were exposed, one plate had a number designation and the other was designated by the number and a letter, i.e., 1 and 1A.

resembles ozone injury; however, microscopic examination has shown it to be distinctly different from the markings caused by ozone in California (P. R. Miller, personal communication).[8] A manuscript by Miller concerning these needle markings has been prepared for publication. In addition, plant pathologists at the Rocky Mountain Forest and Range Experiment Station expect to do some additional work in determining the cause of these needle markings (J. M. Staley, personal communication).[9]

For a survey of this type, the plants themselves proved to be the best monitors of SO_2 injury. Sulfation plates are not sensitive enough to monitor plant injury, even though a relationship appears to exist in some areas between high sulfation rate and plant injury. These plates can best be used to determine general SO_2 dispersion patterns, and, thereby, are useful in identifying areas which have potential for SO_2 injury. Where information is needed about the severity and duration of particular fumigation episodes, more sophisticated equipment is needed.

Certain plant species were particularly useful as indicator plants. Brickelbush appeared to be the most sensitive to SO_2. Other plants which appeared sensitive to SO_2 were skunkbush, cottonwood and willow saplings, and velvetweed.

PLANS FOR FUTURE WORK

Future air pollution estimates for the Southwest are somewhat uncertain. Several existing sources are scheduled to reduce emissions, but other new sources are expected in the near future. In addition, estimates differ as to probable oxidant-type pollution levels resulting from population increases in urban areas. Based on the results of this survey which show that forest vegetation is not presently being killed by air pollution, and on estimates of air pollution for the near future which indicate that air pollution levels are not expected to increase greatly, we plan to do the following:

1. Continue the Region-wide detection survey; however, place emphasis on monitoring vegetation in selected observation areas where injury has been found, and on collecting background information in areas where new sources are expected in the near future. Specific observation areas where additional monitoring will be done are indicated in Table 27. In addition, background information will be collected in the vicinity of the Phelps Dodge smelter in Hidalgo County, New Mexico, during the summer of 1973.

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[8] Paul R. Miller, Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, Riverside, California.
[9] John M. Staley, Plant Pathologist, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Table 27.--Schedule for future air pollution monitoring.

	Survey area	Observation area	Remarks
Group I	Aztec Ruins Nat'l. Monument	1	Examine areas and install sulfation plates for 1 year after San Juan Station begins operation.
	Chuska Mountains, Navajo Indian Reservation	1, 2	
Group II			No additional monitoring anticipated.
Group III	Lake Mohave Ranger District, Lake Mead Nat'l. Recreation Area	1,2,4	Continue collecting background information during summer 1973. Install sulfation plate station in area 1 for 1 year after Mohave Station begins full capacity operation.
Group IV	Glen Canyon Nat'l. Recreation Area	1, 2	Continue collecting background information during summer 1973. Install sulfation plate stations in both areas after Navajo Station begins operation.
Group V	Silver City Ranger District, Gila National Forest	9	Install sulfation plate station for Apr.-Sep. operation. Examine area in summer 1973.
Group VI	Santa Catalina Ranger District, Coronado National Forest	1	Continue sulfation plate station during Apr.-Sep. Examine area in summer 1973.
Group VII	Clifton Ranger District, Apache National Forest	5, Route 666	Install sulfation plate station in area 5 for Apr.-Sep. operation. Examine areas in summer 1973.
Group VIII	Globe Ranger District, Tonto National Forest	6, 9	Continue sulfation plate stations during Apr.-Sep. Examine areas in summer 1973.

2. Continue to keep informed of oxidant levels in urban and nearby forest areas. Oxidant injury in urban areas will probably precede oxidant injury to forested areas.

3. Continue to work closely with forest disease research personnel to determine if and how foliage analysis data can best be used in evaluating the effects of a new SO_2 source on surrounding vegetation.

ACKNOWLEDGMENTS

We want to thank those individuals, in the Forest Service, the National Park Service, and the Bureau of Indian Affairs, who participated in the survey. Their assistance in identifying survey areas and changing sulfation plates was invaluable. Likewise, we would like to thank Robert D. Alley, of the Arizona Department of Health, for the assistance he provided, particularly in the early stages of the survey. Dr. Roger L. Caldwell, University of Arizona; Dr. John M. Staley, Rocky Mountain Forest and Range Experiment Station; Dr. Paul R. Miller, Pacific Southwest Forest and Range Experiment Station; and Dr. Walter W. Heck, Agricultural Research Service; all provided valuable suggestions and advice. Finally, thanks are due Melvyn J. Weiss, Forest Service, Southwestern Region, for his continued interest and guidance throughout the survey.

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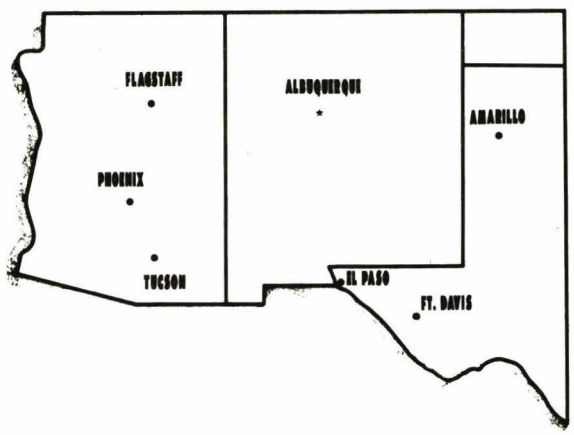

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